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Worldwide, hydroelectric energy from dams has gained unsustainable momentum. Nearly two-thirds of the world's large rivers in the northern hemisphere are fragmented by dams. The neotropics are now the primary frontier for dam construction and development. In Chile, hydroelectric energy is considered a Non-Conventional Renewable Energy and a gateway to "clean energy". This misconception has led to serious ecological, environmental and recreational degradation. The growing demand for water at a time of concerning hydrological conditions has increased water's economic value, as well as the intensity of social and political conflicts. A new hydropower boom is raising new challenges for water governance in Chile. As an international leader of neoliberal law, Chile operates by merging water, electricity and natural resource policies within the frameworks of economic law. In order to foster sustainable energy development while maintaining productive and healthy ecosystems, it is critical to understand the ecological, environmental, and recreational impacts from hydroelectric damming. Through the use of Geographic Information Systems (GIS), this research provides a novel and interdisciplinary approach to identify, model and quantify the impacts of a proposed hydrodam on the Teno River, Chile.

KEYWORDS: Free-Flowing Rivers, GIS, Dam Modeling, Hydrodams, Hydroelectricity, Environmental Impacts, Ecology, Recreation, Ecotourism, Domestic Tourism, Biodiversity, Geological Instability, Conservation.

ENVIRONMENTAL, ECOLOGICAL AND RECREATIONAL IMPACTS OF A PROPOSED HYDROELECTRIC DAM ON THE TENO RIVER, CHILE

by

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Approved by

Rick Bunch
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To my family, for our blood runs wild as the free-flowing rivers.

APPROVAL PAGE

This thesis written by Dominique Haller has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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PREFACE

> Biologists link the natural hydrograph of rivers- ranging from high to low flows on an annual basis- to that of an electrocardiogram. Its vacillations, which some people regard as annoying, are as important to the rivers as the heartbeat is to the patient (Palmer, 2004).

As a young child, I rejoiced uncovering the submerged secrets of the rivers. I remember at barely four years old, standing on a rock by the current, watching my father and his Olympic whitewater teammates smoothly train through the artificial polls hung from opposite river terraces. The waters mentoring their every move. During that time, on a warm afternoon, I launched myself into the waters, risking all of my earthly self, and ventured to touch and feel the colorful depths that amused me. I learned to swim by accident and was amazed by how naturally my arms and legs coordinated, dancing swiftly across the stream. I was indulged by the caress of the river and spent every summer from that point on discovering its depths, observing the birds as they bathed and peeled the periphyton from the rocks, the fish as they danced about the waves, standing still at times to face the current, mouths wide open, ready to catch a desolate insect from upstream. My siblings and I tasted the Pangue plant as they hung graciously from the river banks, with their palmate leaves shading the sides of the channel, nurtured by springs falling from the terraces above. It was all an interwoven revelation to me, the rivers were the source of life to everything around them, carving the unabating mountains, giving rise to floodplains filled with blackberries, kuyi flowers and manzanilla, among many other species that served as shelter to the foxes and hares nearby.

In the winter, I learned to cherish and respect the indomitable strength of the waters. Mountain excursions were daily adventures for my siblings and me. Sometimes, heavy rains would break the clouds, and the streams would suddenly grow. Ephemeral channels would form on our path back home, and we would be forced to enter the currents, holding each other’s hands with a bamboo shoot on the other, attempting to reach the other side. On many occasions we got dragged by the flow and were left with battle wounds we would later get scolded for. And in those long winter months, I would learn to fish, to manufacture a fish holder with branches, to recognize the catch, and after a soft prayer, to gut it and prepare it for the fire. These fishing trips were the pride of my family, it brought us closer together and allowed our elders to teach us, and us to listen carefully, delivering a powerful ode. Sometimes we would find “Piñachas,” a sweet water crustacean, much like a crab, but much harder to find as they live in narrow cold channels and hide under the sediment. Over a decade later, I can almost feel them pinching my hands.

My appreciation and devotion for the Teno and Claro Rivers manifested at an early age. I believe it was instilled in me through my mother. The sounds of the waters accompanied me all throughout my childhood, and my mother always encouraged me to listen, to sing and to dance along with them. But I wasn’t the only one enchanted by the riveting flow. The sights of the Tricahue Parrot breaking the winds above impregnates the essence of the rivers, adding to their mystical beauty. The rivers nurture their flight as the birds orchestrate the meandering of the lifelines below. For as long as I can remember, we would run outside to meet their sight as soon as we heard them approach, those loud and wildly birds, always flying in pairs, altruistic in nature. They would come around bursting out the colors of the earth, colors of olive green, yellow, bright blue, red, orange, with a distinct white circle around their eyes, which distinguished them from all other parrots in Chile. They would come down to the village and perch in the “Aromo” trees, striking at the yellow flowers, or hop around the ground looking for fallen walnuts, buckeyes and hazelnuts. It was such a sight to see! It made you feel as if they were sent from above to brighten up the earth and spread colorful seeds of wonder. I understood then, almost two decades ago, the sacredness of the Tricahue and their inherent role as guardians of the Teno and Claro rivers. For as long as the Chilean people have inhabited the region, this ravishing bird has been the emblem and the voice of Los Queñes. Without its presence, the rivers mourn, and the essence of the village is lost.

> Without draining the reservoirs, no one can replace lost wildlife habitat, but threatened habitat elsewhere can be protected as part of the bargain (Palmer, 2004)

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CHAPTER I

INTRODUCTION AND BACKGROUND

While water and energy needs in developing countries are real and need to be addressed, the risk to ecosystems is acute and some unique species and habitats are threatened. (…) People are equally vulnerable; not only those who are displaced by dams, but also those who depend on these freshwater ecosystems for their livelihoods. Those most affected by dams still do not necessarily benefit directly and often remain without access to power and clean water (Schelle, Collier, & Pittock, 2004)

Figure 1. Chilean Condor Gliding Over the Teno River, Los Queñes, Chile. Photo By eb.creatives.

Statement of the Problem

Hydro-electricity provides a tentative solution to fossil fuel dependency and is regarded by many as a form of renewable energy. In the wake of climate change mitigation, hydroelectric power derived from dam and river impoundments has skyrocketed. Currently, more than ⅔ of the world's free-flowing rivers in the northern hemisphere are dammed. Formal practice has shown that hydroelectric development completely transforms the natural dynamics of flow and flooding patterns of entire watersheds.

Dams can serve multiple functions ranging from electricity generation, irrigation, recreation, flood protection and may function as cooling agents for industrial processes. Hydropower can be implemented on a moving body of water at different scales, such as run-on-the-river schemes, or can involve the construction of a reservoir (Ansar, Flyvbjerg, Budzier, & Lunn, 2014). The former involves the implementation of weirs in the stream current to harness the energy. This practice yields insufficient electricity and does not uphold investment costs. Other approaches couple weir structures with dams and may serve as a source of energy to nearby hydroelectric plants.

Dams may serve agricultural purposes, safeguarding the provision of irrigation water, especially in areas marked by uncertain precipitation patterns, thus maintaining a perpetual supply of water during periods of low rainfall. In other cases, reservoirs are used solely as thermal buffers for industrial plants, acting as cooling agents. Reservoirs have been used in the protection of low lying coastal areas from flooding, generating dykes that may expand for tens of kilometers in range, drastically changing the geomorphology and chemistry of surrounding water bodies, especially estuaries and their biodiversity. Despite the practicality of dams, the environmental impacts associated with their construction and operation phase have proven to be highly unsustainable (King, Brown, & Sabet, 2003).

From an Environmental Standpoint

Dam construction causes irreversible ecosystem change at various temporal and spatial scales. Dam construction depends on topographic relief, requires highly sensitive engineering models and depend on an infinite supply of freshwater. Because urban development requires a continuous electricity supply, hydroelectric dams are used to complement fossil fuel derived energy and offer the advantage of providing a reliable source of freshwater. Freshwater reservoirs support the amenities of cooking, washing and cleaning, as well as hydration. However, in rapidly expanding urban areas, the mismanagement of reservoirs is a common mishap and can have adverse consequences for the environment and local population. Studies indicate that reservoir mismanagement can lead to degraded reservoirs harboring algal blooms, bacterial growths, and habitat suitability for organisms carrying viral infections. Doctor and author William Jobin has found that fluctuating water levels of many tropical reservoirs create excellent breeding grounds for disease carrying life, with reported outbreaks of malaria, AIDS and other newly emerging diseases in the riparian communities nearby (Jobin, 1999). The root causes across Dr. Jobin’s research translate into a lack of reservoir planning and mismanagement of hydroelectric dams. Mismanagement of outflow discharge further aggravates the disrupted stream channel, contributing to a downstream flow of contrasting thermal profile, devoid of nutrients and sediments, with minimal stream flow capacity, unable to support native biota and ecosystem services (Baurer & Stolyarov, 1961).

From an Ecological Standpoint

Dams displace entire biological populations. Their construction requires the flooding of natural habitats, and in some areas, deforestation that precedes the flooding. The deforestation process is achieved by clear-cut methods that further decimate populations of insects, reptiles, amphibians and land-dwelling organisms, or can be achieved by the massive burning of the area, contributing to greenhouse gas (GHG) emissions. Moreover, the construction process of a reservoir calls for the modification of ecosystem services, introducing exotic vegetation for bank stability or fish assemblages that overthrow the natural framework of a stream. This may result in an ecological shift from specialist organisms to generalist roles, as well as the displacement of endemic species by non-native populations (Studds, DeLuca, Baker, King, & Marra, 2012). The ecological hazards associated with water impoundments are difficult to assess as their externalities expand longitudinally across entire river systems, laterally into the adjacent floodplains and vertically, modifying groundwater supply (Ansar et al., 2014).

From a Recreational Standpoint

Reservoirs may serve as artificial lakes boosting the aesthetic value of a region, allowing for the development of boating and angling activities. The slope and velocity requirements of a dam are comparative to those of effective whitewater sporting activities. Chile has a climatic pattern that mobilizes East –from the Pacific Ocean to the

Andes Mountains – trapping clouds and humidity West of the Andes. This promotes soil and climatic viability in the intermediate depression or longitudinal valley, producing a Mediterranean climate characterized by high seasonal precipitation and snowfall over the Andes. These climatic effects promote and sustain the extensive hydrological network that bathes the region. The majority of the Central and Southern scenic rivers of Chile still run wild and uninterrupted from their origin in the high Andes peaks to their confluence with the Pacific Ocean (Bauer, 2009). In their descent, these lifelines carve and aggrade the landscape, creating multiple ecosystems that harbor a vast array of species, promoting recreational fishing, wildlife appreciation and the creation of protected areas and national reserves for environmental conservation.

The construction of reservoirs is a global phenomenon. Europe alone accommodates over 7,000 dams standing at 10-15 meters high with thousands of additional smaller impoundments scattered throughout the Alps, where altitudinal gradients favor hydropower generation. These smaller impoundments are very influential as a whole, impairing entire hydrological networks and their floodplains (Fishman, 2011). Germany is home to over 200,000 impoundments expanding over 400,000km in length. Spain is considered to have the largest number of reservoirs mostly used for agricultural development, with 1,200 impoundments fragmenting river connectivity across multiple watersheds. Despite having the greatest number of reservoirs, water problems in Spain remain unresolved. In 2008, reservoirs in the capital city of Barcelona were 80% empty. Desperately, the government invested $208 million in the construction of a pipe to haul water from a nearby river. To complement the effort, the Barcelona water company brought water in by ships from the Spanish city of Tarragona, down the coast of Barcelona, and from the French city of Marseille. Barcelona invested an additional $32 million on port modification to receive the cargo. Weekly water shipments were priced at $30 million, with several shipments being hauled into the city every week. The first ship to arrive supplied 5 million gallons of water into Barcelona's municipal system, and the following ship added another 9.5 million gallons. The water supply lasted 32 and 62 minutes, respectively (Fishman, 2011). This environmental catastrophe is a great example of reservoir mismanagement and lack of planning. It cost Barcelona millions of dollars in infrastructure, agricultural losses, and incorrigible river diversion, yet the problem is not resolved. Currently, efforts are aimed at water desalination from the coast, and financial incentives are starting to favor technological novelties. The city is learning from the past, adapting and projecting into the future.

A similar example is observed in the Balkan mountain range in Bulgaria, home to the last free-flowing rivers in Europe. With incredible waterfalls and healthy flows, these rivers are valued merely by their human amenity and their sequestration is expected to allocate over 1,600 new hydropower plants, of which half will be located in areas previously designated as protected habitats. The Balkan Mountains are surrounded by four powerful seas: Black, Aegean, Ionian and Adriatic. With incredible advances in tidal energy sequestration, it would be a deceitful act to dismantle the natural framework of these wild and scenic rivers and their outlets, as opposed to harnessing renewable energy from available tidal power.

Europe is not the only continent to suffer from the over exploitation of its once free-flowing rivers. Reservoirs behind the world's large dams now cover almost 600,000 km^3, an area nearly twice the size of Italy (Catlin, 2009). With a heavy concentration of dams already in place in the northern third of the world, the Neotropics are now a primary frontier for new dam construction (Finer and Jenkins, 2012).

Dams in Chile

Extending 4,270km long, Chile harbors over 12,000 km^2 of freshwater, over 6,000km of highly productive coastlines, and a total land area of 756,102 km^2. Hydroelectric energy in the country is viewed as a solution to power shortages and as a gateway to "clean energy," however, the ecological, environmental and recreational implications of such a technology are seldom considered. The growing demand and competition for water at a time of concerning hydrological conditions has increased water's economic value, as well as the intensity of social and political conflicts. The nation currently operates 38 major hydroelectric dams (> 40MW), representing a total of 7,055 MW of installed hydropower capacity. *Table 1* depicts the geophysical characteristic of Chile. A recent hydropower boom is raising new challenges for water governance and for Integrated Water Resource Management (IWRM)-the current international standards for water reform in Chile (Bauer, 2009). As an international leader for neoliberal law, Chile operates by merging water, electricity and natural resource policies within the frameworks of economic law for which policymaking favors rampant exploitation. The neoliberalist qualities of Chilean politics were adopted at the beginning of the 1980s and originated from the displacement of the former populist government overtaken by the Military branch (Hilbink, 2007). Within this process, Chile's free market economy was established, redefining the value of pristine natural resources to favor their use solely as amenities. In an attempt to define the nature of neoliberalism, scholars have dissected the term into six categories covered within its definition, these are: 1. Privatization: Assigning private property rights to social or environmental phenomena previously state-owned, un-owned, or communally owned. New proprietors may or may not be national entities; 2. Marketization: assigning monetary value to phenomena previously shielded from market exchange. Prices are set by markets at national or global scales, making neoliberalism geographically unbounded; 3. Deregulation: eliminating the interference of the state in numerous areas of social and environmental life, empowering proprietor's self-governance; 4. Re-regulation: deployment of state policies to facilitate privatization and marketization; 5. Market Proxies in the Residual Public Sector: the remaining public services managed by the state set along privatization standards to ensure efficiency and competitiveness within the business economy; 6. The Construction of Flanking Mechanisms in Civil Society: State promotion and encouragement of charities, Non-Governmental Organizations (NGOs), communities, etc. to compensate for social inequalities caused by the previous categories (Castree, 2008)**.**

The current policies governing natural resource availability in Chile have proven to be unsustainable and pose an imminent threat to freshwater ecosystems and their productivity. In order to foster sustainable energy development, it is critical to understand the ecological, environmental, and recreational impacts that hydroelectric damming imposes on undisturbed riverine communities.

Table 1. Geophysical Characteristics of Chile

Chile	
Land Area	743,812 km^2
Water Area	12,290 km^2
Total Area	756,102 km^2
Land Boundaries	6,339 km
Coastline	6,435 km
Lowest Elevation	Pacific Ocean (0)
Highest Elevation	Nevado Ojos del Salado (6,880 m)
Length	4,270 km
Average Width	175 km

Los Queñes is located at the eastern limit of the VII Maule Region, at 34km from the Argentine Republic. This area is renowned for its hydrological richness, providing rivers with a series of rapids and challenging pool-riffle structures, a class III and IV river scheme. In 1985, the US Olympic Whitewater Slalom coaches selected the Teno and Claro Rivers to train their professional team, where several of its members received World Champion titles, gold, silver and bronze medals. These events boosted the popularity of the rivers and eventually, the first whitewater company was established in the heart of Los Queñes in 1992. The company mentored local “Queñinos” and introduced whitewater sports into the community. Ecotourism in the form of rafting and kayaking in the Teno and Claro Rivers developed along with trekking, cycling, horseback riding, excursions, and wildlife sighting activities in Los Queñes. With abounding natural resources, this riverine community has developed an identity with the rivers at heart, becoming a tourist attraction and contributing to the local economy.

The benefits from utilizing the force of the rivers for their recreational value adds cultural and economic value to the region, enabling locals to develop businesses catered to tourists. Some of the local businesses include restaurants, food trucks, leather and wood work, handcrafted jewelry, knitting and sowing, among other customary practices. Tourism sustains four camping sites, cabins, local grocery stores, and other outdoor activities carried out by locals. The community and their sense of place is driven by the appreciation of the available natural resources and is sustained by tourism activities. At the core of their productivity is the free-flowing nature of the rivers.

The name “Los Queñes” has its roots in “Mapudungun” –the Mapuche native tongue– meaning “Twin Rivers.” It is home to approximately 270 individuals and is preferred habitat for many amphibians, reptiles, and mammals, including: the endemic and endangered subspecies of the Tricahue Parrot *Cyanoliseus patagonus bloxami* (figure 2); the endangered Correntino Duck *Merganetta armata armata* (figure 3); the near-threatened national icon, the Condor *Vultur Gryphus* (figure 4); the vulnerable Chilean puma *Linnaeus* (Figure 5); the Culpeo Fox *Lycalopex culpaeus* (figure 6); and an endemic marsupial, the Llaca *Thylamys elegans* (figure 7). It is renowned for its wild rivers, active volcanoes, and unique wildlife. Given that hydropower production requires a steep elevation gradient, this region of Chile is under constant threat by the invasive fragmentation of damming (Finer and Jenkins, 2012). Agricultural fields of cherry, strawberries, apples and grapes downstream from Los Queñes support reservoir construction on the Teno River to offer a reliable freshwater supply for crop irrigation and livestock security.

Figure 2. Tricahue Parrots in their Burrow. Photo by: Cristian Vergara Núñez

Figure 3. Correntino Ducks Courting. From left to right: Confronting Males and Female. Photo by: Mariano Costa

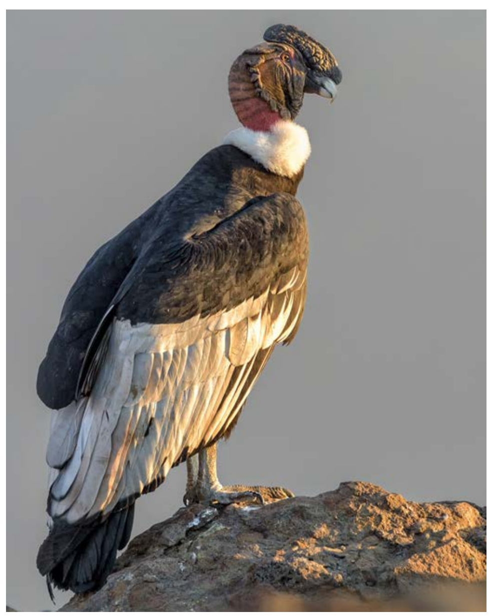

Figure 4. The King of the Andes, Condor. Photo By: <u>Jérémie Goulevitch</u>

Figure 5. The Chilean Puma. Photo by: Miguel Fuentealba.

Figure 6. The Culpeo Fox. Photo by: Javier Gross Feller

Figure 7. The Endemic Marsupial Llaca.
Photo by: Diego Alberto Reyes Arellano

Plans for hydroelectric development on the Teno River have failed to integrate the livelihoods of this local town and its two remarkable lifelines. Patterns of miscommunication and selective disclosure of environmental assessments on behalf of the hydroelectric company have created tension between those who believe the project to be beneficial and those who deem it calamitous. The environmental and ecological assessments have been carried out by the company's own personnel, which creates the need for public scrutiny. The local individuals who oppose the dam have initiated a movement known as "Los Queñes sin Represas" ("Los Queñes without Dams") and have sought national support from various grassroots organizations and NGOs including: Riverkeeper Alliance in Patagonia, Fundación Hualo, Bestias del Sur Salvaje, Puelo Patagonia Corporación, NGO Conservación Andina, Round River Conservation Studies, Etica los Bosques, and many other environmentally driven networks that recognize the need for an alliance. These efforts have recently reached the headlines of regional and national newspapers causing public conflict, both within Chile and internationally. The grassroots organizations and NGOs have integrated their vision into one powerful and interdisciplinary network of professionals and advocates called “Red Nacional por los Rios Libres” (“National Free-Flowing Rivers Network”). The civilian work undertaken by local communities is a clear manifestation of the mission to protect their free-flowing rivers.

The town is also home to the “Aduana,” a National Monument that served until the 1960s as the customs office for cattle passage between the 46km stretch separating Chile and Argentina. The Aduana was erected from rock and concrete in 1860 and began operating in 1864. This monument compliments the region’s national value as a tourism destination that followed almost a century later and remains an important geographical and political boundary. After receiving several impacts from earthquakes, the Aduana monument has been remodeled in the image of its historical infrastructure and remains a source of community pride. Recently, the Chilean government assigned 99 million Chilean pesos for the construction and development of a museum and nature center that will utilize the foundation of the Aduana, enforcing and adding to the existing infrastructure. *Figure 8* illustrates a historical image of the Aduana Monument. *Figure 9* shows the passage of cattle in the one-street segment of Los Queñes, in front of the Aduana Monument.

Figure 8. The Aduana Customs Building in Los Queñes. Google Images.

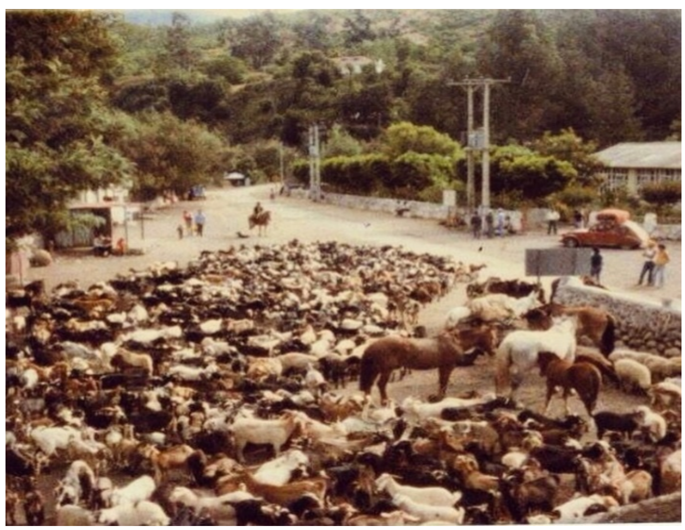

Figure 9. Cattle Passage in front of the Aduana Monument

Objectives

The objective of this research is to examine the impacts of hydroelectric damming operations and river fragmentation on the Teno River and to disclose the ecological and environmental impact assessments to the entire community. This paper is the first to expose potential recreational, environmental and ecological impacts of such an invasive project given that the internal impact assessments performed by the damming company remain obscure to the communities affected. Drawing from previous research in areas with similar topographic and climatic qualities, this paper evaluates the potential consequences of hydroelectric damming on riparian biodiversity, aquatic ecosystems and the local community of Los Queñes. Though there is increasing awareness of the relationship between declining water levels and disturbance of riparian ecosystems caused by dams in existing literature, this line of research remains incomplete. Empirical evidence suggests a range of inconclusive results when weighing the benefits and drawbacks of dams. Answers vary from beneficial recreational development in the form of artificial lakes, agricultural development favoring crop irrigation, economic growth from energy security, contrasted by community displacement, microclimate adjustments and severely degraded watersheds. These inconsistencies exist due to the limitation of datasets, different methodology, scientific bias, variations in geography and climate and the scale being used in evaluating this type of research. This paper contributes to the geoscience discipline by concentrating on the physical and environmental impacts of hydropower on a pristine riverine geography through the use of geospatial analysis and Geographic Information System (GIS) at the watershed level. This is the first attempt at an interdisciplinary approach for this type of research in Chile and in Los Queñes. Very specifically, this research will accomplish the following goals:

1. Investigate and apply previous research on hydropower development both on local communities, as well as local biodiversity, with a focus on the endemic and endangered Tricahue Parrot colony residing on the Teno River at the proposed dam location.
2. Delineate the watershed area using GIS modeling and current digital elevation models, identifying and highlighting the Teno River's hydrological network.
3. Delineate the Tricahue Parrot home-range within the watershed area as it overlaps with the planned hydroelectric dam location, stressing their vulnerability.
4. Elaborate a Hydroelectric dam assessment depicting the expected area that will be flooded, projecting environmental and ecological consequences for the fragmented river-system and its associated watershed.
5. Estimate and assess possible risk of reservoir retention wall failure and flooding of the Los Queñes community.

The project's ambitions are to collect extensive academic literature on hydroelectric damming in Mediterranean climates such as the Maule region of Chile, where the Mataquito watershed is located. The database produced can be utilized and updated in further collaboration from federal and regional agencies, NGOs and data stewards, with the purpose of integrating the highest quality of geospatial data. This study supports an interdisciplinary approach to data collection and interpretation to aid in conservation efforts and serve as a valuable resource for the local grassroots and environmental movements in Chile in their continued efforts to protect free-flowing rivers.

<u>Hypotheses</u>

Throughout human history, experimental practices have shaped the foundation of our current operational systems. Despite great technological development, we continue to entertain archaic forms of energy generation, disregarding the availability of renewable forms of energy. In the case of fossil fuels, continuity of use may be driven by economic incentive and estimated reservoir abundance, generating global discord targeting underdeveloped countries (Water, 2003). It is crucial to meet the energy demands of urban development, but to do so, we must consider the natural environment, learning from the past and imitating successful undertakings in renewable energy development.

This research states the hypothesis that the presence of a reservoir located in the selected transect of the Teno River will result in an environmental hazard. Given the ongoing seismic and volcanic activity within a 6km radius of the retention wall, the site is subject to geological instability that will compromise the dam structure. In 2008, a magnitude 5.2 earthquake shook the area with an epicenter at 2.8km from the proposed retention wall location. This earthquake was followed by a 5.5 magnitude at 7km South, and three additional epicenters of 6.5, 5.1, and 5.1 within a 25km radius. In the event of reservoir failure, the local town just 4.3km downstream will face catastrophic flooding from the dam outflow. Additionally, the proposed location for the dam requires the flooding of a protected site where an endangered and endemic species of Parrot resides, violating federal law and displacing the native population of the bird. Additionally, the dam will create a series of geomorphological changes that will result in lower water tables, inefficient flows to sustain aquatic and riparian biodiversity, impairing the historical whitewater practices that fuel tourism and the microeconomy of the area (Naiman, Decamps, & Pollock, 1993). Moreover, the risk of reservoir mismanagement could result in a rampant growth of disease carrying organisms that threaten the health of local communities (Baurer & Stolyarov, 1961). In conclusion, this research does not support the construction of a dam in the Teno River, as the risks and hazards associated with the dam are overwhelming.

Assumptions

Ecological

The "La Jaula" colony is composed of 201 individuals of the Tricahue Parrot *Cyanoliseus patagonus bloxami* subspecies. The colony inhabits the Teno River terraces and relies on the riparian vegetation and surrounding landscape for feeding and courting. Their habitat coincides with the proposed dam location and will be flooded. This preventable ecological disturbance will force the colony to evacuate their burrows causing population displacement. Individuals with restricted movement – such as injured individuals, newly hatched or vulnerable fledglings, and eggs – will be killed. It is assumed that the displacement of the Tricahue colony will have a cascading effect on lower trophic levels as the Tricahue colony controls insect populations in various larval stages and supports native vegetation through seed dissemination throughout the extensive riparian corridor.

Environmental

> Deposition in reservoirs has effects far downstream as it cuts global sediment flow in rivers by more than 25% and reduces the amount of silt, organic matter and nutrients available to alluvial plains and coastal wetlands downstream. As a result, some coastlines are eroding at rapid rates (Catlin, 2009).

The construction of a dam in the Teno River will bring about catastrophic environmental changes. The flooding of the area will initially contribute to Carbon emissions from deforestation and possible burning of the area and to methane emissions from decaying vegetation and organisms. The operation of the dam will disrupt the supply of freshwater downstream from the retention wall with permanent consequences on the aquatic and riparian biodiversity (Campbell et al., 1975; Raymond et al., 2013). This pivotal reduction in water volume will affect flow velocity and capacity, thus inhibiting channel formative processes such as pool and riffle structures essential for early fish stages and macrofauna, point bar deposits, and other channel structures (Campbell et al., 1975). The water released from the reservoir will be devoid of nutrients, phytoplankton and other complimentary sediments that sustain the trophic cascades of the stream (Biswas, 1969). It will also have a contrasting thermal profile compared to the upstream regime. The natural scouring and deposition patterns of the Teno River will be shifted and the natural geomorphic structures of the channel will not be carried out; the river will lose its natural dynamism. Extensive silting may accumulate in the reservoir, depositing in the bottom of the dam and layering overtime, affecting the operation of the plant as sediment may throttle the feeder tunnels, erode guide vanes and runner blades.

The disruption of the natural flow regime downstream from the dam will result in a loss of native biodiversity, allowing for the introduction of exotic and generalist species, inflicting a homogenization of the freshwater biota (Poff et al., 1997).

Recreational

> The development of tourism in a destination involves a chain of products and services to provide tourist reception at the local, regional, national and global level. It mobilizes the receiving community and its citizens, connected or unconnected to this activity, experiencing transformations of their everyday landscapes to promote tourism and welfare of the tourist (Milagres & Souza, 2012).

Although local ecotourism companies do not employ a significant number of locals, the industry attracts tourist populations all year long. These external populations contribute to the microeconomy by purchasing products in the local grocery stores and restaurants while supporting profitable outdoor activities such as camping, trekking, cycling, zip lining, horseback riding and whitewater recreation. The local brewery that produces the "Cerveza Tricahue" ships its unique beer flavors to the nearby cities of Romeral and Curicó, benefitting from the ecotourism component of the place and further promoting the richness of the town. In the summer months, Los Queñes hosts the "Festival del Loro Tricahue", or Tricahue Fest, held annually as tribute to the Parrot. The planning and development of the festival employs locals in the areas of gastronomy, leather and wood carving, arts and crafts, knitting, music entertainment, and promotes overall community appreciation of the local customs. Similarly, Los Queñes hosts an annual River fest, calling for competitive athletes from all over the country and abroad to participate in the areas of whitewater rafting and canoe slalom. The River fest brings about additional exposure of the local community to the tourist influence and hosts a series of musical and folklore events where local and national bands participate. In response to these activities, an assumption is made between the perceptions of the local community in relation to tourism: This research assumes that the community adapts to the tourism exposure by augmenting local aesthetic value through decorations, enforcement of police surveillance, and engagement in entrepreneurial activities. Tourism centered on the Teno and Claro Rivers functions as an essential lifeline to the village. Since Hydro-electric schemes and whitewater kayaking are directly proportional to topographic relief at the site, and to river discharge (Hynes & Hanley, 2006), it is assumed that hydropower generation and optimal quality of whitewater sports cannot exist simultaneously. When weighing the benefits provided by each undertaking, the disadvantages are unique to hydroelectric damming.

CHAPTER II

REVIEW OF THE LITERATURE

Environmental

Nutrient and Sediment Load Characteristic of Manmade vs. Natural Lakes

Modern reservoirs are built to fulfill socio-economic purposes that include recreation, navigation, and the steady production of large-scale hydroelectric energy. The construction of dams and reservoirs for energy generation and irrigation is one of the oldest forms of human engineering. Historically, dams and reservoirs have been built primarily to irrigate crops, to control floods and to secure water supplies. As technological novelties developed, elevation gradients were found to accelerate water velocity up to a level sufficient for the rotation of man-made water wheels, thus generating hydroelectric energy (Baxter, 1977). Today, reservoirs may be built solely to buffer waste-heat dissipation of an adjacent hydroelectric generating plant. Reservoir flow release are adjusted according to the dam function and depend upon prevailing climatic conditions. Dam flows that have been built to mitigate and prevent catastrophic flooding are immediately released after a flood. These flash flows are damaging for the in-stream and riparian biodiversity, scouring riverbeds and tearing root systems (Baxter, 1977).

The physical and chemical properties of manmade reservoirs are unparalleled to those of a natural lake. Water entering a dam has a very different thermal profile than the dam water, it has a different sediment content and sediment type, and consequently, varies greatly in water density (Churchill, 1947). The shoreline of a man-made reservoir is almost always higher as the reservoir fills to its intended capacity. The tributaries flowing into the reservoir will be scoured upstream and the impounded water will begin "backing" into them, forcing the development of a dendritic network pattern, subject to underlying geological characteristics. The longitudinal profile of a fragmented river will differ greatly from natural lakes; where natural lakes have higher depths near the middle, man-made reservoirs are deeper just upstream from the dam and are often referred to as "half lakes" (Ackermann, White, Worthington, & Ivens, 1973). In this deeper area, surface currents entering the reservoir do not dissipate in shallow water as they do in natural lakes. Contrarily, these currents may be deflected downward or reflected backward at the dam, creating point source pressures[1] on the dam wall (Baxter, 1977). The shoreline modifications in a man-made reservoir are initially very high due to the constant changes in water levels to achieve optimal reservoir volume, driving erosion processes. The shoreline inside of the impoundment will be reduced over time given the exhaustion and resistance of the geological material along the edge of the impoundment (Coakley & Hamblin, 1970). Generally, this stability is reached after all the softer materials have been eroded and dissolved and only harder materials remain.

Sediment transport is unique to each channel, it is a crucial formative driver for the creation of channel structures that enables in-stream habitats, disperse materials

[1] Measurement of the fluid pressure in a porous reservoir. The reservoir pore-fluid pressure is a fraction of the overburden pressure that is supported by the fluid system. The other portion is supported by the rock and generates in-situ rock stress.

downstream and provides the overall circulation of debris and materials throughout the network. Various methods of sediment transport have been recognized in the literature, including bedload sediment,[2] and suspended load.[3] The latter is blocked upon contact with an idle body of water, such as a dam, decreasing its velocity and facilitating deposition, forming deltas. When the gradient of a stream is gradual, sediment deposition tends to extend upstream from the dam, sometimes for several miles. When this occurs, the stream loses capacity[4] and becomes susceptible to flooding at high flows (Baxter, 1977).

Most natural lakes have limnology[5] patterns ascribed to the forces of winds and to the effects of thermal circulation and prevailing climatic conditions. The situation in reservoirs is drastically different as limnology patterns are subject to retention times, which in many reservoirs is fairly short and dependent on inflow and outflow rates, with outflow discharges restricted to a point at some depth below the surface. Water is almost always stratified within the reservoir, due to the absence of natural flows and depths, and the outflow may draw from a thin layer of laminated water, creating internal currents (withdrawal currents) characterized by limited vertical movement within the reservoir.

In an attempt to understand and explain the complex limnology of man-made reservoirs, researchers use the term “density currents”. Incoming flows of water do not mix with the stagnant and colder body of water within the reservoir. Instead, incoming

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[2] Relatively coarse material pushed and rolled near the stream bed.

[3] Finer sediment moved through siltation or suspended in the flow.

[4] Stream capacity refers to the amount of sediment that a given flow is able to transport.

[5] Limnology is the study of interstitial and below surface waves and patterns of water movement.

flows scour around, beneath or above the mass of stagnant water (Baxter, 1977). The Tennessee Valley Authority (TVA) guarding the Tennessee River and its tributaries (the most dammed river system in the contiguous United States) was the first to identify this phenomenon in the Norris Reservoir, the largest storage reservoir in the system. These density currents have been described as: “A convergence line of ten (that) appears where the inflowing water plunges below the surface. A compensating upstream current is generated, carrying back debris which are immobilized where the two currents meet, making a convergence line visible even if its position has not already been revealed by a difference in turbidity between the inflowing and the surface water” (Baxter, 1977). Other currents have been identified, such as the turbidity current caused by incoming flows with high density of suspended sediment. These currents may extend for the whole length of the reservoir or lake, such as Lake Mead, where turbidity currents reach over 160 kilometers in length. Turbidity currents contribute to flow patterns within the reservoir, modifying channel velocity and density, and can carry silt for long distances, depositing some of the content along the way, and in turn, adding to the formation of bottom set deposits (Churchill, 1947).

The chemical properties and concentration of natural lakes are subject to the characteristics of the incoming flows, runoff inputs, and precipitation. Comparably, new impoundments concentrations are determined by the leaching of soluble material below the ground on which they are located, and other landforms and vegetation that have been flooded (Baxter, 1977). If the soluble material is limited and the retention time is rater short, this chemical influence may be brief. In Lake Mead, the materials flooded were highly soluble and had a long retention time. Consequently, the lake has an impoundment chemistry and concentration that differs dramatically from incoming waters. The in-stream organisms that are sustained in the upstream waters may not survive once entering the reservoir.

> The decomposition of submerged vegetation often leads to a depletion of oxygen in the depths of the reservoir. The peculiar profile of most reservoirs, as compared with natural lakes, may permit the accumulation of a mass of stagnant water in the deepest part against the dam. This bottom layer can become anoxic, and reduced substances such as sulfide, ferrous, and manganous ions may accumulate (Baxter, 1977).

Long standing reservoirs have been characterized by improved water quality that benefit commercial and domestic use. This is because the suspended particles have enough time to settle, allowing for greater control of bacterial growths, and improved dissolved oxygen concentrations. This explains why long-standing reservoirs often have lighter and transparent waters. Newly made reservoirs vary substantially. Here, initial levels of dissolved oxygen are eliminated, and the water is mixed with leachate from humic substances within the soil. Given the leaching effects of underlying terrain and vegetation, it is common practice to strip the region prior to the construction of the dam (Campbell et al., 1975). “The nature of this practice depends among other things on the nature of the soil, climatic conditions, and the retention time of the reservoir”.

> Many of the effects produced by dams on the stream below them are the reverse of those produced on the lake above them. What is retained in the lake (heat, silt, inorganic or organic nutrients) is lost to the stream (Baxter, 1977).

Downstream of the reservoir, outflow exhibits an inverse variation to the annual discharge values within the impoundment. Downstream flows are devoid of organic detritus, decreasing heterotrophic activity vital to a natural regime. In an effort to mitigate the undernourished outflows, a new source of plankton detritus has been developed to be added to reservoirs prior to water release. The amount of primary production downstream may be favored due to the lack of turbidity and sediment (allowing for greater light infiltration), as these have been retained at the dam, however, if planktonic activity is high within the impoundment, primary production cannot be sustained downstream by the limited water nutrient content (Beiningen & Ebel, 1970). Thermic activity within the reservoir is influenced by seasonal conditions and have a direct impact on the downstream temperature regime. The epilimnion of the reservoir will be heated during summer months, while the hypolimnion remains undisturbed. The epilimnion acts as a heat trap, leading to an outflow marked by cooler temperatures as water draws from the lower, dense layers. Throughout the winter months, the thermal stratification will have broken down and some of the heat stored will be added to the outflow (Baxter, 1977). The effects of which will create warmer flows during winter season. These thermal patterns defy the natural characteristics existing prior to the impoundment.

Climatic variability induced by impoundments remains an understudied subject in hydrology. Climatic changes attributed to man-made reservoirs have been identified in the past and are found to be proportional to the size of the flooded area. These changes are driven by an increase of stratus clouds and fog, which directly impact temperature and modify annual precipitation patterns. In high altitudes, these alterations lead to a delay in the beginning and termination of the growing season. Additionally, studies have identified seismic activity induced by large impoundments of water (Baxter, 1977). These influences are difficult to assess and mainly focus on the point source pressures of groundwater in rock fissures, enabling slippage in areas of formal geomorphological fractures, aggravating pre-existing geological stresses.

Much remains to be learned regarding the development of small and large-scale dams: how flooding will influence local fauna, how river fragmentation will impact fish runs, and the overall livelihood of the communities dependent on these resources. The best attempt to address these concerns is to intensify investigation efforts aimed at all possible aspects of the ecology of the region at risk.

Market vs. Ecological Value of Free-Flowing Rivers

The major threat to Norwegian rivers, as in the neotropics, is the development of hydroelectric dams for energy generation. Recently, river and environmental conservation in Norway has shifted toward an integral approach at the catchment level scale, incorporating entire hydrological networks. The socio-economic transition of Norway from a predominantly agricultural society to an industrialized economy has been possible due to hydroelectric development. Over 50% of Norway's energy comes from hydropower, making it one of the wealthiest nations in terms of energy resources in the world. The damming of wild and scenic rivers has become a highly controversial topic in as is also the case in Chile. Due to this rapid and unprecedented shift, environmental efforts have been initiated on behalf of these river systems that hold high tourism value and that support the survival of anadromous fish and endemic organisms (Huse, 1987).

> The very rivers which after development represent one of the most valuable economic assets of Norway, represent a different set of unique values in the natural state (Huse, 1987).

Norway has the highest electricity consumption per capita of the world, and the favoring climatic conditions marked by high precipitation patterns and steep gradients favor hydroelectric power over other forms of energy generation. There are no major fossil fuel power plants within the nation, and although future plans involve imports of natural gas from the North Sea, environmental studies are still underway to assess potential impacts. In 1970, over 50% of the hydropower potential in the country was reached. At this rate of development - increasing by 6% a year- the remaining free-flowing rivers would be exhausted within a few decades. At this time, politicians began questioning whether economic value continued to dominate over the environmental and ecological value represented by the rivers, and the decision to propel hydroelectric dam construction became a matter of parliament (Huse, 1987). In addition to creating reservoirs at the hydraulic head of rivers in the high mountains, dam developers have supplemented the practice by diverging tributary flows into complex artificial tunnels that connect other reservoirs and neighboring power stations. This is often necessary to meet the demand of the metallurgical industry, primarily aluminum, as Norway became an important contributor after WWII. The divergence of stream flows has deprived many valleys of their annual flooding regimes, eliminating the characteristic landscape features and floodplain ecosystems previously valued for their ecological and scenic attributes (Huse, 1987). A tentative solution to this streamflow diversion practice is a demand to maintain a minimum baseflow enough to support in-stream biota. However, accurately determining the formative baseflow of a stream is an arduous endeavor.

Strong opposition to hydroelectric power development came at the turn of the 20th century. This opposition has been led by scientists and nature conservationists and has gained the support of the Norwegian people. Throughout the 1970s, public protests took the center of attention in opposing new dams, a form of unprecedented public involvement in the natural resource management area of Norway. The movement integrated ethnic and tribal populations, whose livelihoods were at stake and whose voices were silenced. Governmental industries, and the Norwegian Hydroelectric Board (NVE), with the help of politicians and conservationists reached a consensus to safeguard many free-flowing rivers for ecotourism and ecological value (Huse, 1987). The evaluation of these rivers set aside for protection does not include water diversion for irrigation and cultivation, for which a need for new legislation on river exploitation is underway (Wildlife, 2003).

Environmental Flow Assessments for Rivers

King introduces a practical and novel methodology, DRIFT (Downstream Response to Imposed Flow Transformation) for advising on environmental flows for rivers targeted for water-management activities. DRIFT's basic philosophy is that all major abiotic and biotic components that constitute an ecosystem should be managed, including the full spectrum of flows, and their temporal and spatial variability.

> Environmental flows may be defined as water that is left in a river system, or released into it, for the specific purpose of managing the condition of that ecosystem. During the last five decades, about 100 different approaches have been described for advising on environmental flows, and more than 30 countries have begun to use such assessments in the management of water resources. (King et al., 1999).

The methodology used in the study employs experienced scientists from the following biophysical disciplines: hydrology, hydraulics, fluvial geomorphology, sedimentology, chemistry, botany and zoology. In regions marked by subsistence users of the river, the following socio-economic disciplines are also employed: sociology, anthropology, water supply, public health, livestock health and resource economics. The interdisciplinary nature of King's study adds to its credibility and makes it an integral reference for environmental flow assessments.

The problem of flow assessment and management is especially concerning in developing countries of semi-arid climates, where rivers are targeted for hydroelectric development and the fast-growing population receives minimal domestic water allotments (King, et al., 2003). Many of these countries acknowledge the need for environmental protection to ensure optimal management of their natural resources but are limited in their understanding of environmental management systems and lack the necessary tools to create them.

The interdisciplinary approach characteristic King's study allows for professionals to undertake their own research and provide unique methodologies while reaching similar conclusions on the ideal flow regime for a given river. Their results are measured in terms of *frequencies, timing,* and *duration* of different magnitude flows needed to achieve and maintain a specified river condition. As a consensus, four different flows have been identified and described in terms of their environmental and ecological influence: low flows, small floods, large floods, and fluctuating flows. *Low flows* or daily flows are the base level of the channel and provide stability to the streamflow in response to dry and wet seasons and degree of perennially. The different magnitudes of low-flow in the dry and wet seasons create more or less wetted habitats and different water-quality conditions, which directly influence the balance of species at any time of the year. *Small floods* are ecologically important in semi-arid areas in the dry season. They stimulate spawning in fish, flush out poor-quality water, mobilize and sort soil particles, enhancing physical heterogeneity of the riverbed while contributing to flow variability and bed roughness. These flows are able to reset a wide spectrum of conditions in the river, triggering activities as varied as upstream migrations of fish and the germination of riparian seedlings. *Large floods* trigger many of the same responses as small floods, but additionally provide scouring flows that influence the form of the channel. They mobilize coarse sediments, and deposit silt, nutrients, eggs and seeds throughout the floodplains. They inundate backwaters and secondary channels, and trigger bursts of growth in many species. These flows recharge soil moisture levels at the banks, completely inundate floodplains, and scour estuaries, maintaining hydrological links that may extend to the sea. *Fluctuating flows* have the power to change conditions on a daily and seasonal temporal scale, creating mosaics of areas inundated and exposed for different lengths of time (King, et al., 2003). The resulting physical heterogeneity determines the local distribution of species; with the notion that higher physical heterogeneity enhances biodiversity.

Water-resource development is expanding fast, but the operative mechanisms to provide management and protection of freshwater lack a deeper understanding of the subject. This uncertainty is probably greatest in semi-arid regions, where hydrological unpredictability is high, and in developing countries, where data may be scarce (King, et al., 2003). The choice for aquatic scientists and hydrologists to determine and advise on optimal flows lies somewhere along the spectrum of giving no advice until more data are available, to advising within the limited understanding of the watershed.

Environmental Flow Dynamics and the Hyporheic Zone

King and Brown focus on the complexity and interconnectedness of the physical and chemical characteristics of a stream channel, highlighting the role of the hyporheic zone (HZ). Research has expanded our knowledge of the HZ, defining it as a nutrient rich layer of interchanging gases between the channel bottom and the permeated layer below. This area is vital to macroinvertebrates providing readily available nitrogen, organic residues and shelter. When a streamflow is diverted or reduced, the effects are mirrored in the HZ. The gas and nutrient exchange becomes limited, and reliant organisms are displaced as their habitat is no longer supported. Drained river beds result in the loss of invertebrates and nutrients as the channel loses viability (Beiningen & Ebel, 1970). Additionally, when the river bed is lowered, the groundwater portion of the stream is extracted by capillary forces away from the banks, promoting bank instability, erosion, and eventual collapse. The floodplain recedes into a desert as groundwater supply is unavailable for rooting systems, substituting riparian gardens for decrepit soils. These changes occur overtime and may be difficult to identify on a short temporal scale (King & Brown, 2006).

In river science, disturbances are met with a series of positive and negative feedbacks within the system in search for a dynamic equilibrium. Within the stream channel, the viability of the ecosystem is reliant on the functioning of all its physical and chemical components. Riparian vegetation for example, requires high groundwater levels to maintain root stability. This hydrological nourishment enables riparian species to store beneficial forms of nitrate in their leaves, which fall into the stream as labile organic matter. Once in the system, leaves are colonized by fungi and bacteria with specialized digestive enzymes, able to combine the detritus with available organic waste, creating powerful nourishment for insect larvae. Larvae in turn, feed dozens of species of invertebrates and fish. These relationships harbor a complex pattern of mutual enrichment that is maintained by the natural flow of the stream channel. A powerful illustration of this phenomena is described by biologists Mark Sosin and John Clark who reported that:

> A 10-pound northern pike requires 100 pounds of minnows that ate 1000 pounds of invertebrates that ate 10,000 pounds of aquatic plants. The good pike stream must be a good insect stream, and before that, a good algae stream, and before that, a good water stream with adequate variation of flows based on the pattern of the millennium (King & Brown, 2006).

Within King and Brown's research on hyporheic processes, they have made a powerful contribution to hydrological science by synthesizing hydrological data in a way that other scientists can utilize to project flooding patterns and impact assessments.

Utilizing current and historical flow data is a practical approach to elaborate hydrological models, facilitating environmental planning and estimations of water supply. Hydrological data can be acquired from flow duration curves (FDCs) to yield values covering a given period of choice (daily, monthly, seasonal, and yearly time-scales) and can be used to rank discharge values of a given stream. FDCs are highly beneficial for ecologists in order to assess how a planned flow change will affect a river ecosystem and allow for mitigation planning (King & Brown, 2006). The data is interpreted by professionals and rearranged to estimate flow changes and their influence on a river ecosystem.

The study of FDCs introduces a hydrological approach to categorize the variability of streamflow according to their unique role in maintaining river ecosystems. Every geography is unique to its flow categories, and some may have more than others. South Africa contains over 10 different flow categories. This is due to climatic variability between the wet and dry seasons, and to the fact that most rivers are relatively short in their longitudinal profiles, having flashy hydrographs and limited floodplains. Hydrologists conclude that "the more unpredictable the flow regime, the longer the record needed to obtain a reasonable summary of conditions" (King & Brown, 2006). The study of different flow categories has opened a new door in river conservation. Understanding the flow regime nature of a river helps us make accurate predictions regarding the health of waterways, safeguarding environmental and ecological aspects (Budge, 1967). These aspects include nutrient concentration responsible for algal blooms, and better quantification of sediment, estimating clogging, deposition and scouring processes. Understanding these components can help determine the vulnerability or abundance of freshwater species. Furthermore, the ability to predict river changes helps in planning for rural properties and users of the river.

> In developing countries, there are likely to be very high numbers of rural people who depend on river resources for their livelihoods. (...) Rivers are prominent in health, cultural, religious, and recreational aspects of their lives. Until very recently, water resource developers have not taken into account the possible downstream impacts of river changes on such people (McCully 1996, World Commission on Dams (WCD) 2000).

The Drawbacks of Manmade Reservoirs

After over a century, scholars have finally set out to uncover the hidden costs imposed by the building of reservoirs and their associated developmental processes. Rivers were the lifeline of continents, providing transportation pathways, facilitating the exchange of goods, the development of agriculture, complementing human dietary needs and serving as waste disposal sites. Historically, rivers have fostered healthy and growing communities all over the world, empowering some of the greatest civilizations of all time. Out of the 150 largest US cities, 130 are located along river systems. Despite their indispensable value, humans have failed to recognize the toxic overloading of waste and pollutants released into river systems, both directly and through surface runoff from adjacent impervious surfaces, undermining channel integrity, in-stream organisms, floodplains and riparian vegetation, as well as soil characteristics (Palmer, 2004). For centuries, humans have tempered with the intricate and essential nature of hydrological networks with utmost disdain.

> No one has calculated the losses of rivers and river life to power dams already built, yet hydro projects have been a source of destruction to America's native landscape dating back to the nation's first power plant, which was located in the Fox River in Wisconsin and lit 250 light bulbs in 1882 (Palmer, 2004).

In the United States it is common practice to divert stream flows for irrigation elsewhere, leaving a dry and corrugated river bed resembling an aquatic genocide. This practice, in the words of Tim Palmer: "Creates the ecological absurdity of a river in a pipe". In highly urbanized areas, streams may be channeled into a network of pipes and sewage lines under the impervious sea of cement, out of sight, and consequently, out of mind. In areas were reservoir construction is imminent, the flooding required for such development changes the landscape irreversibly, blocking the passage of piscivorous migration paths, and the downstream movement of smolts, destroying a biological legacy.

The water stored in a reservoir is released downstream according to human demand, at the expense of the stream and riparian communities. Reservoirs may restrain the release of water during periods of low electricity demand, creating a shallow riverbed exposed to the sun and high temperatures, with a significant decrease in velocity. These changes reduce the natural geomorphic patterns of scouring, deposition, sediment transport and the formation of channel structures. Conversely, during periods of high electricity demand, water is flushed out of the reservoir in large quantities, eroding terraces, floodplains, and channel beds, displacing boulders and many riparian and aquatic assemblages, including essential stocks of periphyton[6] (Palmer, 2004).

Although hydroelectric power does not require the combustion of fossil fuels, it is not a benign form of electricity production. It does contribute to greenhouse gas emissions by incorporating methane into the atmosphere from inundated vegetation. Hydroelectric energy generation is at the expense of entire riparian ecosystems and in-stream communities. During the construction of a reservoir project, slope failure and erosion is a high risk (Coakley & Hamblin, 1970; Naiman et al., 1993). The unprecedented channel rises necessary to fill the reservoir may weaken the adjacent terrain and saturate the soil, causing major landslides and hill slope collapse. Evidence of such an event can be found in the construction process of a proposed dam in the Fall River in 1992 in the Western United States. The dam was set to generate 7.5 megawatts (MW) of power, and the flow of the river would be diverted. The diversion began scouring the natural embankment of the channel, causing a massive avalanche of water, boulders, mud and vegetation that eliminated twelve miles of the previously pristine river, with debris reaching as far as the Henry's Fork of the Snake River (Palmer, 2004). Attempting to tame or control free-flowing rivers is an unsustainable and preposterous act. Learning from these failures can help us protect threatened watersheds moving forward, encouraging sustainable development and prioritization of freshwater integrity.

[6] Microscopic to macroscopic algae growing on the stream bottom, attached to various substrate. Most abundant and diverse autotrophic group in streams.

Dams and Ecosystem Change

Various studies have attempted to describe global problems regarding freshwater conservation and management. It is generally accepted that the rapid declines in freshwater quality worldwide are mainly attributed to stream diversion and severe river fragmentation. Over 60% of the world's largest rivers are currently diverted from their natural courses, and their flows are restrained in man-made reservoirs and artificial lakes. With exponential population growth, global demands for energy and electricity continue to escalate. Approximately 2 billion people in the world have no access to electricity, 1.1 billion people lack access to potable water, and over 2.4 billion people are denied basic sanitary services unique to freshwater (Schelle et al., 2004). These compelling data urgently call upon natural resource and freshwater management. Countries with developing economies have become targets for reservoir and dam construction, fulfilling energy demands for foreign industries that exploit their natural resources while degrading the environment and local community. These communities are often brainwashed as being leaders in the achievement of “clean energy” for their countries and lack education and political and economic support to fight back multinational companies (Schelle et al., 2004).

Over 45,000 large dams remain operational in over 150 nations (Ansar et al., 2014). Approximately 1500 hydroelectric dams are currently in the feasibility phase or under construction. Of the latter, nearly 400 are sizeable, with walls extending over 60 meters in elevation. With over half of major rivers already damned and exploited for energy generation, further development in river fragmentation is shifted to developing countries and financed by major economies such as the United States, China and India. The Yangtze River in China has been exhausted in hydropower capacity, with 46 additional dams under environmental assessment and planification. La Plata Basin in South America has been fragmented with 27 large reservoirs, followed by the Tigris and Euphrates Basin in Turkey, Syria and Iraq. The underdeveloped river systems in Africa stand out for the lowest number of large dams planned or under construction, making it appealing for modern dam suitability and development (Schelle et al., 2004).

Moving forward, we must exercise the expertise gained through various techniques in dam construction, favoring those with minimum environmental impact. Hydroelectric endeavors have led to the development of environmental management and cautionary principles that may reduce the impacts of damming operations. Based on these experiences, the World Commission on Dams (WCD) has elaborated a set of recommendations to improve decision-making and aim to reach all nations involved. To avoid large-scale damage at the watershed level, preliminary studies and decision-making must include comprehensive alternatives and impact assessments, including social, ecological and cumulative assessments of planned dams at the river-basin scale (Dams, 2000; Schelle et al., 2004). The use of GIS is a powerful tool to enable these assessments through dam modeling, coupled with Integrated River Basin Management (IRBM), providing the necessary guidance to minimize basin wide impacts, while meeting the needs of stakeholders and the nearby population. These methods, however, are absent in developing countries. This unreliability creates inadequate mitigation predictions, especially in underdeveloped nations where there is no legal requirement to do so.

Precautionary principles and best management practices for reservoirs are gaining momentum, demonstrating that it is possible to find a balance beneficial to both the environment and urban development (Dams, 2000). Parallel to better management practices, the WCD has established guidelines to increase the likelihood of risk and impact mitigation and promote environmental and human safety (Schelle et al., 2004).

Achieving a reduction in damming operations based on their construction costs and amounts of wastewater is the ultimate global objective. The overall water efficiency of reservoirs used for irrigation is a staggering 38% according to the United Nations (2003). Considering that over 70% of dams are utilized for this purpose, this percentage is of great environmental concern, translating into 1500 trillion liters of water wasted annually (Clay, 2013). Efforts to increase the water efficiency of dams through technological improvements that minimize or capture water losses is a critical need. Technological improvements favoring water efficiency have been implemented, drip irrigation systems for water intensive crops, such as cotton, translate into water savings of up to 80% compared to conventional flood irrigation systems, but these techniques are out of reach for most small farmers and underdeveloped nations.

> This unacceptable wastage of valuable water is driven by misplaced subsidies and artificially low water prices, often unconnected to the amount of water used and needs to be addressed urgently (Wildlife, 2003).

Reservoir management and dam technologies have improved over time. Appropriate site selection (avoiding impoundments on the main stem of a river system), better design with multiple outlets and ecological considerations (such as building fish passages for anadromous species), may play significant roles in minimizing impacts. Hydrological data may help managers imitate the previous natural streamflow, working towards maintaining temperature and oxygenation of water released downstream (Schelle et al., 2004).

In places like the Kafue Flats in Zambia, with worldwide recognition for their ecological richness, the construction of two dams in 1969 and 1976 wiped out several rare endemic species, and affected the local industries of floodplain agriculture, dry season cattle grazing and traditional fisheries. Following the reservoir placement, the natural water regime of the Kafue Flats was drastically diminished and natural floods were replaced by a monotonous flow (Schelle et al., 2004). The changes in the natural flow regimes caused a decline of many species, lowered fish yields, and reduced the customary practice of cattle grazing during the dry season.

Hydroelectric Dam Construction Boom

Zarfl and colleagues have provided a global summary of hydroelectric development for the recent past and current decade. The researchers estimate that 22% of the world's hydropower potential has already been exploited with yields of approximately 15.6 million GWh (=106 kWh) per year. The unsustainable exploitation of freshwater has created unprecedented economic, ecological, and social ramifications worldwide (Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2015). In order to comprehend global investments on hydropower dam construction and existing hydropower reservoirs, Zarfl obtained data from approximately 500 investors beginning in 1978. The data included: investor's name, country, year of investment, name of project, and amount spent in US dollars. This information was combined with geospatial data to identify exact dam locations and helped discern the current development of hydroelectric power and the social, economic and ecological implications associated with the construction of reservoirs.

Geo-referenced data was prioritized for future dam constructions with power generation of 1MW or greater, dams that produced less were excluded from the study. The data collection for dams in construction or on a late planning stage were carried out between August 2012 and February 2014. This process involved several approaches, including: 1. Peer reviewed literature 2. Government documents 3. NGO reports and publications 4. Newspaper articles 5. Commercial databases 6. Reports of energy producers 7. Reports of energy infrastructure engineers or consultants and, 8. Other web sources. Dams in a final planning stage were only reported if they provided an assessment for social, cost-benefit and environmental aspects. Dams at a pre-feasibility stage were not included (Zarfl et al., 2015).

Spatial information was based on the World Geodetic System of 1984 (WGS 84) coupled with geo-referencing processes through a GIS, referencing original data sources literature and Google MapsTM or Google EarthTM. Most of the spatial data acquired was aligned to the HydroSHEDS global river network, with the exception of 12 records that were beyond the extent of the HydroSHEDS. HydroSHEDS allowed for the cross-validation of dam locations by using additional data sources. Attribute data on dams was recorded and included name, location, main river system, major basin and sub basin, stage of construction, maximum electrical yield (MW), dam height (in meters), start of construction and projected completion date.

The findings of the study showed an average of 3,700 major dams in the world ranging from 1MW and higher in production. These are either operational or in construction and are located primarily in developing nations with early economic development. It has been projected that upon completion of these dams, hydroelectricity production will increase by 73%, yielding approximately 1,700 GW annually. The study found that this significant increase in hydroelectric energy generation will reduce the remaining number of the world's last free-flowing rivers by 21%, while having little to no influence in closing the electricity demand gap we face today. The dams will not eradicate energy related conflicts and interdependencies and will not contribute to the reduction of GHG emissions. In fact, earlier studies have detected average CO2 and methane emission rates of 85 g and 3 g per kWh (with an uncertainty factor of 2) of produced hydropower electricity. What this means is that the projected dam constructions based on investments will generate an additional 280–1,100 Tg[7] of CO2 and 10–40 Tg methane to the atmosphere. This translates into an increase of 4-16% of global carbon emissions associated with anthropogenic bodies of water (Raymond et al., 2013).

The highlights of Zarfl's study showed that developing regions, such as the Teno and Claro Rivers region of Chile, are subject to hydropower expansion driven by foreign and private economic interests that compromise local hydropower potential and export it to the industrial sector. In countries like Kenya and Tanzania, with electrification rates of

[7] 1 Tg = 1012 g

approximately 20%, the provision of energy for their populations is already supplied by the existing dams, however, energy corruption from mining companies exert pressure on the existing energy grid, creating an energy shortage that transgress local populations (Zarfl et al., 2015)

<u>Ecological</u>

Threats vs. Conservation Efforts for the Tricahue Parrot

Figure 10. Tricahue Burrows. Google Images.

Barria and colleagues set out to produce a thorough profile of the *Cyanoliseus patagonus bloxami* colonies of the Vallenar, La Higuera, and La Serena counties of Northern Chile, where illegal chick extraction has been significant. The Tricahue Parrot is the largest parrot found in Chile, and it is also the scarcest, with populations plummeting annually. Currently listed as endangered, the parrot is subject to chick sequestration for the international pet trade, hunting, and habitat destruction, despite being under conservation priorities in the regions of Atacama, extending south into the Maule region. Historical archives show that the Tricahue Parrot had a long biogeographic range that encompassed coastal cliffs and valleys from the Northern III region of Atacama, all the way to the XIV region of Los Rios in the South. Today, the subspecies is virtually extinct below the VII Maule region, and it is found in isolated and disjunct populations throughout its remaining biogeography (Barria, Cea, Moller, & Santander). *Figure 10* shows a Tricahue Colony in their burrows. The population estimates from the years 1984-1985 have been the lowest ever recorded, with 3,265 parrots. With the help of molecular genetics, and following conservation efforts, the population was estimated to be between 5,000-6,000 parrots in 2011. In most recent years, however, Tricahue populations are suffering another significant decline mainly due to the illegal pet trade market and habitat degradation.

The parrot exhibits habitat preferences unique to the Maule region, including Mediterranean climates, arid and semi-arid habitats with a secured stream network nearby. The species conglomerate in "loreras" which are defined as elaborate interconnecting tunnels located on earthen riparian cliffs. Each colony is characterized by gregarious individuals inhabiting a similar region that nest together on the same cliff. The reproductive seasons identified by Barria fall between the winter months of July-August and into late spring in December, with non-reproductive periods falling between January through June. Variations in population size detected in this paper are attributed to changes between the reproductive and non-reproductive season, as well as displacement and migration patterns either seasonally or during the reproductive season. As detected by Barria, the Tricahue displays a pattern of winter or seasonal migration, during which colonies abandon the "loreras" and expand their foraging grounds. This migration is usually a vertical migration towards higher elevations, often in response to changes in urban development, as well as food availability. It has been observed that the colonies of the Tricahue seem to be larger during the winter compared to summer months and it is uncertain whether climate change is exerting ecological pressures on the species.

Biogeography and Evolutionary Divergence of the Tricahue Parrot

Figure 11. Monogamous Pair of Tricahue Parrots. Google Images.

Masello and colleagues utilize molecular genetic methods in their study to compare and identify ecological and evolutionary patterns of the *Cyanoliseus Patagonus* subspecies. Genetic structuring of species is influenced by environmental conditions (climate), as well heterogeneity of habitat, physical and orographic barriers and distribution of resources (Masello et al., 2011). The high Andes of South America, reaching elevations of up to 6,900 meters above mean sea level (amsl), may constitute a significant barrier for species dispersal. Genetic structuring is expected to dominate in species with geographic restraints, which isolate organisms and shrink their genetic pools. When divergent populations regain contact, a hybrid zone may develop with consequences for the interbreeding populations (Masello et al., 2011). *Figure 11* shows a monogamous pair of Tricahue parrots. The hybrid species may overpopulate and displace original populations, or in the event of limited geographical ranges, the hybrid zone may act as a channel for genetic exchange, increasing the phenotypic variation and genetic richness of the populations. Studies focusing on the Pleistocene era and associated phylogeographic patterns such as geographic expansion, species fragmentation and secondary contact, are undertaken by Masello, focusing on the *Cyanoliseus patagonus* species, or “burrowing parrot”. This avian species is known to be restricted to annual precipitation patterns averaging 600 mm and annual temperatures of no less than eight degrees Celsius. The burrowing parrot can be found in the high Andes of both Chile and Argentina; however, higher elevations and air currents permanently limit the distribution and contact between the neighbor populations. On the Chilean side, climate is predominantly Mediterranean, with “matorral” vegetation adapted to dry conditions. The parrot has been found to be critically dependent on water, hydrating continuously throughout the day (Masello et al., 2011). They require earthen cliffs, riparian terraces, and sandstone or limestone areas in order to nest.

> These specific requirements for nest sites, which are spread over thousands of square kilometers, and water, together with the colossal barrier of the Andes, may favor the isolation of burrowing parrot breeding sites and a complex population structure driven by genetic drift (Masello et al., 2011).

The heterogeneity of habitats found within the geographic range of the burrowing parrot have led to the identification and proposal of four subspecies: three of which are found in Argentina (*Cyanoliseus patagonus patagonus*, *Cyanoliseus patagonus andinus,* and *Cyanoliseus patagonus conlara*) and only one sub-species, the *Cyanoliseus patagonus bloxami,* found in the Andes mountains of central Chile. The *Andinus, patagonus* and *bloxami* are morphologically distinct, with variations in size and plumage coloration. Microsatellite markers have distinguished moderate differentiations between the Chilean *bloxami* and all other subspecies, but differentiation among the Argentinian populations have not been detected. These interrelations may be augmented by incorporating uniparental markers such as mitochondrial DNA which allows for a greater resolution of genetic structure (Masello et al., 2011). The study has found that the *bloxami* species divergence is at the root of the species phylogeny, implying that this subspecies is the only one to not have bared recent population expansion, illustrating a Chilean origin with a single migration vent across the Andes.

> The lack of gene flows makes the high Andes an important barrier to migration in burrowing parrots, and possibly in other bird species. This also renders the isolated bloxami population genetically and phenotypically distinct. This evolutionary significance is important from a conservation and management perspective (Masello et al., 2011).

A significant threat to the burrowing parrot comes from the illegal captivity and pet trade, the persecution of the bird mistaken as a crop pest, and habitat displacement driven by urbanization and landscape degradation. Habitat displacement contributes to the fragmentation of bird populations and loss of species connectivity. Upon abandonment of the nesting burrows, unwanted consequences for other species are often detected. The abandoned burrows are re-occupied by other unwanted cavity nesters such as insects, reptiles and small mammals (Masello et al., 2011).

In Chile, there are only 5,000-6,000 *bloxami* species left between the IV and VII regions whereas historically, the species could be found all along the nation, expanding over 3,000 km. The size and uniqueness of the burrowing parrot population calls for urgent conservation measures to ensure the survival of the species.

Behavioral Patterns of the Tricahue Parrot

Figure 12. Tricahue Parrots Landing on Cactus. Google Images.

This study provides behavioral descriptions of the burrowing parrot as a Psittaciforme[8], social and genetically monogamous bird. The *Cyanoliseus patagonus bloxami* is one of the most southern Neotropical parrots, distinctive to other species as it breeds colonially and excavates tunnels serving as shelter and nesting burrows on earthen

[8] Order of birds including parrots, amazons, cockatoos, lorikeets, lories, macaws and parakeets.

cliffs, limestone and sandstone. The parrots are socially organized in pairs, with one pair per burrow. These nesting burrows have been found to be enlarged every year by the inhabitants (Masello, Sramkova, Quillfeldt, Epplen, & Lubjuhn, 2002). Each female Tricahue is able to deliver up to five eggs, which are incubated for thirty-two days by the female while the male Tricahue gathers food and ensures a continuous supply of water for the female. Parental care in these species is very strong and feeding tasks are shared between the parents. Once the chicks are able to fly, they will remain under the protection of adults for another four months, mimicking their parents foraging and burrowing skills. *Figure 12* shows Tricahue parrots landing on local cactus.

The burrowing parrot is easily disturbed and will leave its burrow even in the midst of incubation and during the first week of the hatching and nestling phase. Despite these disturbances, parrots have high a probability of survival to the next breeding season. Given that the burrowing parrot shows a strong paternity role and are guided by strict genetic and social patterns of monogamy, studies have found that long-living parrots, such as the *Cyanoliseus patagonus* (average longevity of ~50 years) do not invest on broods of doubtful paternity. A female parrot that may exhibit extra pair brooding (EPP) detected from scent, will likely suffer from reduced or absent male parental care. The latter is thought to be tantamount to reproductive success in burrowing parrots because of female incubation reliant on male foraging, food and water supply (Masello et al., 2002).

Riparian Corridor and their Ecological Importance in Regional Biodiversity

Naiman and colleagues attempt to define the ecological term of riparian corridors and their role in developing healthy ecosystems that sustain a vast array of organisms. Riparian corridors are the most diverse ecosystems found on terrestrial earth. These areas are subject to spatial and temporal modifications as they depend on watershed flow regimes from upland and underground sources. Their channels are controlled by elevation gradients and their scouring and geomorphic capabilities are limitless, modifying the riparian ecosystem. For this reason, special attention should be given to the dynamics of riparian corridors and their influence on climate along the fluvial gradient (Naiman et al., 1993). Riparian corridors have a critical role in development planning as they encompass valuable hydrological and landscape areas, and their restoration as well as conservation should be prioritized.

Large riparian corridors are characterized by extensive and well-developed floodplains exhibiting long periods of seasonal flooding, lateral migrations and resembling dendritic hydrological patterns. These conditions support a vast diversity of vegetation supporting all sorts of different terrestrial and aquatic organisms. Channel size, position within the basin, and hydrologic regime are all variables managed by the width of the floodplain (determined by its geological characteristics), the vegetation cover, sedimentation inputs, and geochemical cycles. It is an ongoing process that continuously cycles and shapes the environment. The stream of a riparian corridor has a large impact on environmental regulatory controls (damming effects, sand bars, scouring) habitat formations for aquatic organisms (large woody debris) and terrestrial, as well as microclimates associated to varied densities of vegetation cover that influence temperature and light infiltration. The vegetation along riparian corridors offer valuable ecosystem services through their ability to regulate light intensity, soil resistance to scouring, flow regimes, as well as nutrient absorption (Naiman et al., 1993). In fact, Naiman argues that a great number of land-use impacts on local ecology and environment can be mitigated with effective riparian corridor management.

In the search to preserve biodiversity, we must maintain landscapes that sustain vital ecosystems and whose drainage networks are embedded deeply into the landscape. We are left with the understanding that riparian corridors are extremely sensitive to environmental changes, they are highly dependent on the type of disturbance (mining spill, tectonic uplift, flooding, fires, landslide, channel diversion, etc.), and this directly impacts biotic adjustment to those environmental changes. In North America and Europe alone over 80% of natural riparian corridors have been eliminated followed by land cover and urbanization (Naiman et al., 1993). This calls for immediate conservation efforts with a concentration on hydrologic connectivity and variability from the headwaters to the sea. It is crucial to begin river assessment and management at the watershed level rather than small local and regional levels.

Natural Flow Regime of Freshwater Ecosystems

> The ecological integrity of river ecosystems depends on their natural dynamic character (Poff, et al., 1997).

Despite the extensive historical relationship between humans and freshwater resources, the costs of harnessing streams and channels for human use are finally recognized. The evidence is increasing as we see more streams unable to support life and to sustain ecosystem goods and services. Current land-use management and water policies consider the extirpation of species, closure of fisheries, groundwater depletion, and overall declines of water quality and availability as consequences of formal river management and trends (Poff et al., 1997). Currently, the sustainable management of river ecosystems requires that conservation management must be firmly grounded on scientific development, however, this approach is often challenged. The lack of inclusion of fundamental scientific principles in river management prevent successful conservation and restoration practices as river systems depend on their natural dynamic character.

Streamflow discharge and frequency are considered as major drivers for the ecological integrity of a river system. These components influence the physic-chemical properties of rivers such as water temperature, channel geomorphology, and habitat diversity (Poff et al., 1997). Until recently, this intricate relationship had been ignored, and the ability of streamflow to dictate the distribution of riverine species and to regulate ecological integrity was overlooked. In order to understand the workings of a hydrological network, streamflow gauge observations must include a significant period of time, creating a profile of the stream. For many watersheds, these types of measurements are not available which makes their assessment challenging. Interpolation has been applied in the past involving the practice of extending streamflow data from gauged streams to areas with the similar geographical characteristics, generating a unique estimated profile. Further studies on streamflow in places with no gauge data can be achieved by selecting samples of old living trees that have been damaged by past floods. These techniques can help us extend the hydrological record of a river and provide insight into the natural dynamics within a watershed (Poff et al., 1997).

Rivers and their unique flows show great variability determined by the cross-sectional area of the channel, climate, geology, topography, and vegetation. Places with minimal climatic variability and precipitation yield stable and predictable hydrographs sustained by high groundwater recharge. Conversely, areas marked by seasonal precipitation where streams are dominated mainly by snowmelt, exhibit over-the-bank flows and runoff patterns. Generally, there are five components dominating streamflow: magnitude, frequency, duration, timing, and rate of change of hydrologic conditions (Poff et al., 1997). These components can help us determine the ecological consequences from human modification to any one of the five components. A better understanding of these ecological consequences can be achieved by examining each component individually. *Magnitude* of discharge refers to the amount of water moving past a fixed location per unit time, at any given time interval. It can be absolute, or relative and the maximum and minimum values vary with climate and watershed size. *Frequency* of discharge refers to the occurrence of flows of a given magnitude and its recurrence over a fixed period of time. The frequency of occurrence is inversely related to the magnitude of flow. The average or median flow would be determined by a flow with a frequency of occurrence of 0.5 (50% probability) over a given period of time. The *duration* of a flow is the amount of time associated with a particular flow condition. It can be relative to a flow event, or a composite expressed over a specified time period. *Timing* or predictability of flows with a unique magnitude refers to the regularity with which they occur with reference to different time scales. Finally, the *rate of change* or "flashy" component refers to how quickly a given flow can evolve from one magnitude to another, with flashy streams having rapid rates of change from one magnitude to another. The flow of a river is a combination of surface water, groundwater, interstitial water, as well as the forces that shape the channel structure, and the riparian vegetation that is maintained by the channel (Naiman et al., 1993).

> The predictable diversity of in-channel and floodplain habitat types has promoted the evolution of species that exploit the habitat mosaic created and maintained by hydrologic variability (Poff, et al., 1997).

The effects of human alteration of multiple flow regimes create an imbalance within the natural hydrological patterns that leads to riparian conditions to which the native biota is poorly adapted to. Alteration of sediment movement in a channel disrupts fine-scale geomorphic features and may take centuries before the balance of the formative dynamics are achieved. In some cases, this balance is never attained, and a streamflow may remain in a state of continuous recovery. In the case of dams, these impoundments capture all but the finer sediments moving down a water gradient, yielding sediment depleted water downstream with great ecological consequences (Poff et al., 1997). This sediment-free water erodes finer sediments from the receiving channel, creating and exposing coarse materials in the stream bed. The stream bed and its sediment variability and fine particle content is crucial for the habitat of instream macroorganisms that sustain the aquatic trophic levels. Additionally, finer sediments that may enter the channel downstream from the dam retention wall will be deposited between the coarse particles now found in the channel bed. The lack of flooding events brings adverse consequences to the eggs and larvae of many invertebrates and fish as these organisms require natural scouring patterns and are highly sensitive to sediment aggradation (Poff et al., 1997).

Recent approaches to streamflow management have established minimum allowable flows or viable flows. These are estimated by analyzing historical hydrographs for a given stream and determining the formative streamflow magnitude. Other approaches involve the assessment of changes in river flow and their effect on instream habitat provided by the Instream Flow Incremental Method (IFIM). This method combines a biological model that describes habitat preferences for fish as it pertains to depth, velocity and substrate, as well as a hydraulic model that estimates habitat variability in relation to discharge. Despite modern attempts to identify minimum allowable flows, current river science indicates that instream biota require multiple habitat features that cannot be sustained by minimum allowable flows alone (Poff et al., 1997). The variability of flow is crucial for scouring patterns and to revitalize gravel beds, floodplains, import wood and organic matter, and enable accessibility to fertile wetlands.

Poff stresses the interconnectedness between river usage and flow alteration and calls for an understanding of watersheds, with all the interchanging components of streamflow. With 85% of the continental waterways in the US artificially controlled, this decade is a new opportunity to expand our appreciation and awareness of free-flowing rivers. The growing evidence in support of natural flow regimes and the understanding of streamflow components has allowed for a new way of thinking, based on experiences and lessons from the past. As we move forward with this knowledge, the next century holds a promising opportunity for rethinking our relationship with freshwater ecosystems and biodiversity, favoring both human and environmental resilience.

Hydrological Connectivity and Behavioral Change in Avian Communities

Rampant urbanization has become a cause and effect of fast-growing populations. Urbanization requires an increase in land cover and impervious surfaces that replace green areas and natural vegetation. Recently, the ecological disturbances associated with impervious surfaces have gained attention from scholars and scientists as these impervious surfaces have both direct and indirect impacts on the wildlife and local biodiversity (Studds et al., 2012). Habitat loss and habitat fragmentation are of direct impact as species are physically displaced from their habitats, whereas some may adapt to the perturbation. Indirect impacts are seen in the contamination of water due to increased surface runoff from nearby urban centers, residential and commercial areas, modifying nutrient content, creating negative effects on the dissolved oxygen contents found in the water (Studds et al., 2012) . Hydrological connectivity is increased during long periods of heavy rainfall as these paved areas inhibit soil infiltration. This effect is evident in the existing estuaries, marshes and ephemeral pools in Chesapeake Bay where hydrological connectivity has brought undesired pollution from surface runoff and an alarming enrichment of nutrient content in the water, reducing its natural salinity.

The impact of these hydrological phenomena, including an expected decrease in dissolved oxygen, affect the essential benthic macro-invertebrates guiding the food chains. Due to their primary roles in the trophic level of the food web, these organisms directly affect secondary consumers, bio accumulating through the chain and reaching the highest levels of the food chain. The hydrological amplification is seen in algal blooms, and eutrophication of the water following their decomposition, which is consumed by microbial respiration and leads to hypoxia in the water. Migrating organisms such as crabs, fish and other aquatic species may be able to use this hydrological connectivity to flee the disturbance, leaving higher consumers with a reduced food supply. In order to protect the bird communities and larger species, we must strengthen environmental management standards focusing on lower levels of the food chain (Studds et al., 2012).

Studds and colleagues aimed to understand the effects of land cover increase as they reshape the local avian communities in Chesapeake Bay. To do this, the author makes use of non-metric multidimensional scales to show the impact on estuaries. During the drought of 2002, the selected estuaries exhibited a heterogeneous ecosystem marked by the presence of generalist species, as well as specialists. However, in the following year (2003) heavy precipitation patterns, (third largest one since 1983) increased nutrient intake in the estuaries six-fold. Structural equation models determined that this input to the water source had repercussions on the behavioral and communal patterns previously seen for the local bird communities. Field work included 27 estuaries with an embankment separated from a major tributary in the basin. Land cover was derived using remote sensing procedures paired with GIS from the National Land Cover Database, 30m resolutions. The bird populations were surveyed at 1 km transects along the estuaries focusing on water birds (exclusively aquatic) such as gulls, terns, waders, raptors, kingfishers, and other waterfowl. The transects were surveyed using DOBSERV to calculate abundance estimates and further categorized these estimates to identify estuary composition. Estuary composition was categorized in high scores: supporting a majority of specialists (high conservation value); and lower scores: supporting a majority of generalists (lesser ecological value- according to the study) (Studds et al., 2012). Temporal and spatial variation between the high and lower scores was analyzed yielding compelling results.

During the 2003 drought, minimal environmental perturbation was identified in the estuaries and the number of generalist and specialist in the region was mixed. In the next year, nutrient increases in the water were acute, reflecting high levels of hypoxia and lower salination, causing an ecological shift in specialist waterfowl communities to completely generalist behaviors. Because of a reduction of macro-organisms and benthos, local waterfowl minimized their selective behavior and resorted to feed on available resource, without distinction. As a result, the study shows that increased hydrological connectivity between terrestrial landscapes and aquatic ecosystems significantly lowered the water quality and shifted the composition of water bird communities (Studds et al., 2012). In order to explain this shift in avian ecological behavior and composition, ecological disturbance at the lowest trophic levels must be understood. Some of the species identified to have shifted their eating behaviors were: mute swan (Cygnus olor), Canada goose (branta Canadensis), mallard (anas platyrhynchos), the domestic duck (cairina spp.) This research urges to understand trophic interrelationships within water ecosystems, ensuring the protection and mitigation of ecological threats posed by increasing land cover and urbanization.

Recreational

Hydroelectric Power and Policy in Chile

Bauer shines a light on the market-oriented water and electricity policies for river use and development in Chile. Socio-political tendencies in Chile have favored the development of neo-liberalist policies applied to natural resources in both the water and electricity sectors. As a result, laws and policies in Chile support the privatization of water rights, granting hydroelectric companies access to river fragmentation via impoundments and channel diversions (Bauer, 2009).

The current hydroelectric power boom in Chile has been tied to the weakening economic growth associated with chronic shortages of electric power generation in the past decade. Severe droughts have produced massive blackouts in the capital city of Santiago and neighboring communes. The solution to these power shortages are the construction of dams and reservoirs in central and southern Chile to increase water reliability and energy autonomy. As part of the market-based value of rivers in Chile, the government has approved and supported dam construction, including a 1,200-mile transmission line expected to be built in central Chile, claiming that the economic benefits will outweigh the environmental costs (Bauer, 2009). This assessment fails to recognize the inevitable loss of water and energy throughout the transmission process.

The literature suggests that future water policy and hydroelectric development will be shaped by three independent variables: 1) climate change, 2) privatization of water rights and market-based economy and 3) the role of ecosystem services. These components are expected to drive the interactions between water and energy policies worldwide. The current notion of hydropower in Chile is that this technology is one of the cleaner alternative energies, has limited environmental pollution and contributes negligible amounts of GHGs, making it essential for the transition into energy autonomy. However, hydropower implications are serious and understudied in Chile. A common trend involves the feedback loops between water and energy and its fragility in response to the changing climate. This relationship is often referred to as the water-energy nexus, as water is required to create energy and energy is needed to make water available (Bauer, 2009). Another emerging trend deals with the policies that favor privatization often referred to as "neoliberal" policies. These policies are facing opposition calling for stronger government regulation and environmental protection (Bauer, 2009), assigning greater environmental value to freshwater as opposed to market and economic values alone. Despite the growing opposition, the basic principles established by the market-based economy such as previous trade-offs and resource allocation continue to influence future water and energy policymaking. Lastly, the trend of assigning value to ecosystem goods and services from an economic standpoint is an important driver for new policymaking and political change.

Bauer provides an analysis of the Chilean water code, divided in three political phases in which the electricity and water sector have been modified, opening water rights to foreign entities, displacing government involvement, and returning to a more progressive stand of federal regulation and protection through national parks and reserves. The overall review supports that energy autonomy for Chile is critically devised by water resource availability, and the electric sector does not consider aspects of water rights or management related to environmental, cultural, recreational or ecological implications, favoring solely the market and economic value of freshwater ecosystems (Bauer, 2009). The political instability has caused large-scale social upheaval in the country, forcing the creation of multiple NGOs, coalitions and government agencies set to challenge the environmental assessment reports generated by hydroelectric companies monopolizing the exploitation of rivers. Consequently, a progressive environmental movement has proved successful in challenging and slowing down the hydropower boom, as well as the revision of projected reservoir development and planning, delaying their construction on grounds of insufficient impact assessments and lack of integrated research accounting for ecology and physical environment. Nevertheless, water rights in Chile favor hydropower over domestic water use and freshwater conservation. For water uses other than hydropower, Chile lags with the complete absence of an efficient integrated water management system, weakening the protection of its major free-flowing rivers and continental lifelines.

> Building a reservoir effectively brings a river under the jurisdiction of electricity law. For purposes other than hydropower, however, water regulation is weak whether the issues concern other water uses, integrated water management, or ecosystem support. This is bad news for water sustainability and governance (Bauer, 2009).

Challenges of Hydropower Technology

Bourdeau and colleagues challenge the vision of replacing fossil fuel resources – such as coal and crude oil – with hydroelectric power. The research conveys the perception that achieving maximum hydroelectric potential at an immeasurable environmental cost will contribute less than half of the global electricity demand projected for the year 2040. Conversely, the study predicts that without any additional dam construction, electricity generation worldwide will decrease by 12%. The proposed sites for hydropower development target highly sensitive regions of the world, marked by great ecological richness and abounding natural resources. The challenge to provide large-scale hydro-electricity while maintaining the ecological integrity of the local environment requires transboundary assessments associated to dam construction across river systems. This intercommunication is necessary to reduce environmental impacts, especially in river systems heavily fragmented today (Bourdeau, Corneloup, & Mao, 2002).

Some nations have initiated transboundary communications in East Africa, where future hydroelectric development was abandoned in the last remaining free-flowing river of Rufiji. The local communities worked to protect the Rufiji River and successfully negotiated the allocation of additional hydroelectric development on already fragmented river schemes such as the Nile and Zambezi Rivers. Severe hydrological fragmentation of river systems however, is not the only concern in East Africa. GHG emissions associated with large impoundments, specifically those attributed to carbon and methane emissions, are known to be a factor of reservoir morphometry and the stratified water layer from which the outflow of the dam is released to produce electricity. These stratified layers contain varying chemical compositions and greenhouse gas contents depending on the stratified layer from which it is drawn, ranging from deep hypolimnion[9] to superficial epilimnion[10] layers (Bourdeau et al., 2002). The projected hydropower dams targeting the subtropics and tropic regions of the world are expected to release considerable emissions during the first 5 years of construction, accounting for the vast areas of vegetation that will require controlled burning or flooding prior to construction (Campbell et al., 1975). An estimate from the Intergovernmental Panel on Climate Change (IPCC) predicts that GHG emissions from projected hydroelectric development may exceed the current emissions of fossil fuel combustion tenfold (Bourdeau et al., 2002).

The life cycle of greenhouse gases produced from fossil fuel combustion compared to that of hydroelectric power vary considerably. Studies have shown that hydropower emissions can be up to 30 times lower than coal. This assumption is challenged however, as it does not account for the environmental damage imposed by hydroelectric emissions on freshwater resources, local biodiversity, and ecosystem services. Additional damage includes the relocation or displacement of humans, especially of indigenous people that have developed a culture and lifestyle reliant on these freshwater resources. Riverine communities are burdened with degraded and

[9] The lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.
[10] The upper layer of water in a stratified lake.

diminished freshwater resources and disproportionate economic distributions associated to hydroelectric utility costs (Bourdeau, et al., 2002).

Bourdeau demonstrates that the projected expansion of hydropower capacity will likely fail to close the global electricity production gap. The increase of transboundary hydropower projects instigates socio-economic conflicts similar to those experienced among interdependent fossil fuel and nuclear energy resources. Thus, hydroelectric reservoirs can aggravate the existing rivalry over water resources, need for flood prevention, and food supply (Vörösmarty, Douglas, Green, & Revenga, 2005) emanating from users and stakeholders with differing economic agendas and conflicting interests. The analysis of the study concluded that hydroelectric power alone will fail to (1) to tackle the problems of population growth and energy demand related to climate change, (2) close the electricity access gap, or (3) erase interdependencies for electricity production. Renewable and sustainable energy will be critical to complement projected hydroelectric projects and develop a multi-mode sustainable energy grid.

Despite the renewable aspects of hydroelectricity, this technology brings about severe social and ecological effects, including population displacement and relocation to unfavorable areas, violent transboundary conflicts, fragmentation of river systems and large-scale ecosystem change. These effects aggravate the future of freshwater biodiversity. Vörösmarty and colleagues urgently call for the implementation of sustainable forms of energy a par with hydropower development to optimize the production of alternative and renewable energy while minimizing externalities and environmental impacts. Preliminary impact assessments and reservoir modeling offers valuable insight for hydroelectric engineers and managers, providing an empirical quantification of projected hydropower dam implication. This approach can be interpolated on a global scale with the goal of minimizing impact and further mitigating existing environmental pressures. This allows for a sustainable and systematic management approach that integrates hydrological network effects and cumulative impacts of multiple dams within a catchment system.

Tourism and Long-term Economic Growth in Chile

In the following study, Brida and colleagues provide an empirical assessment of tourism as it influences long-run economic growth in Chile. Tourism in Chile has expanded in the past few decades, with a reported growth of 12% between 2002-2006 (from 1,412 million tourists, to 2,253 million) in 4 years. It has been identified that the exponential economic growth experienced in Chile in the last three decades was complimented by a significant increase in international tourism (Brida & Risso, 2009). Although growth in the tourism sector has been recognized, tourism researchers have not focused on creating empirical assessments of the economic contributions of tourism.

The tourism-led growth hypothesis (TLGH) states that international tourism is a strategic driver in the long-term economic growth of the country and provides an array of benefits, including: 1) significant foreign exchange earnings benefiting capital goods; 2) stimulation for investments in new infrastructure and market competition; 3) employment generation and therefore, income booster; 4) stimulation of research and development, and the accumulation of human capital with developing technical knowledge (Brida & Risso, 2009).

Briso attempts to accounts for real GDP data and real exchange rate (RER) obtained from the Central Bank of Chile for the time of 1988-2008. On that time scale, Briso draws on tourism expenditure data from the World Travel & Tourism Council. Values indicate that the international tourism expenditure for Chile advanced economic growth considerably, rendering tourism as an important economic driver. An emphasis on domestic tourism is advised in this study, presenting the notion that domestic tourism can promote the decentralization of the tourism market and associated infrastructure development while expanding the practice throughout the country (Brida & Risso, 2009). In doing so, former customs of centralized international tourism aimed at popular areas such as the Atacama Desert, Easter Island, Patagonia and the capital, may redistribute economic investments to other ecologically rich areas, furthering tourism development and the appreciation of wild and scenic natural landscapes nationwide. Enforcing domestic tourism is necessary to strengthen environmental and freshwater policies aimed at conservation and restoration, promoting recreational tourism and therefore, economic growth.

Streamflow Influence on Whitewater Recreation

The following review focuses on streamflow policies needed to maintain tended flows benefitting recreational whitewater activities. The relationship between streamflow discharge and recreational quality has been a relevant topic of research, primarily due to the economic incentive behind river science. Additionally, managing streamflow is necessary to provide safe hydrological conditions and minimize whitewater associated accidents or casualties. Studies generally conclude that there is a non-linear relationship between whitewater recreation and streamflow. The recreational quality and satisfaction increases with stream discharge up to a certain point, then it begins to drop as discharge increases. The points of minimum, optimum and maximum flow satisfaction are unique to each river segment and are influenced by climatic conditions influencing the boating trip, biodiversity, wildlife, and scenery (Brown, Taylor, & Shelby, 1991).

It is no surprise that human population growth continues to demand recreational development in the name of river diversions and the creations of man-made reservoirs resembling natural lakes. These demands, require optimal flows for boating satisfaction and often require rigorous streamflow management and reservoir discharges favoring safe and amusing flows. Because of this, the presence of hydroelectric impoundments and recreational boating have to be closely assessed (Brown et al., 1991). In an effort to address this relationship, the Wild and Scenic Rivers Act, Federal Power Act, and other land and resource management policies have been enacted demanding fair and sustainable tradeoffs between the two.

Within the existing literature, studies have focused on determining streamflow thresholds, evaluating recreation quality, estimating aesthetic and economic recreation values, environmental carrying capacities, and other freshwater needs. This study identifies water dependent activities, including recreational boating, sports fishing and swimming, as well as other water-enhanced activities such as camping, picnicking, and hiking. A fundamental distinction is made between streamflow that directly (short-term) influences recreation by promoting high quality boating conditions, fishing success, and scenic appreciation through optimal boating travel times. Other influences are associated with indirect or long-term streamflow effects with long-term recreational impact that may provide optimal channel structures and river morphology supporting healthy ecosystems for wildlife, fish and riparian biodiversity.

Ecological Streamflow Requirements

The following study supports the globally accepted assumption that in-stream biota is intrinsically dependent on fluctuating environmental streamflow. Understanding streamflow requirements to support and maintain aquatic resources can be very challenging. Different approaches have attempted to explain this relationship, with the most common methods focusing on one or two critical resources rather than an integral approach encompassing multiple components. Former experience shows that focusing freshwater management on one resource, i.e. fish integrity, neglects other components, risking environmental degradation of geomorphological processes, alteration of riparian vegetation, and floodplain characteristics (Hill, Platts, & Beschta, 1991). It is essential to redirect research at the watershed level in order to reflect the longstanding influence of climate, geology, topography and the short-term effects of riparian vegetation on channel shape and structures. Literature shows that flows supported by prevalent climatic conditions maintain channel forming processes, such as scouring, sediment deposition, and drainage patterns (Hill et al., 1991).

The role of floodplains within channel integrity is often overlooked and can be useful to assess streamflow effects. The sediment and nutrient transfers allocated in floodplains are essential to the health and support of instream biota. Instream macroorganisms rely on active floodplains for their nutrient intake and habitat conditions.

These organisms support trophic levels, and maintain aquatic productivity associated with higher fish yields. When streamflow is decreased by anthropological forces, access between channel flow and the lateral floodplain becomes limited or altogether eliminated. In this event, both floodplain and channel properties change overtime in response to the disturbed nutrient dynamics (Hill et al., 1991). Overbank flows are responsible for providing fundamental nutrients, organic matter (OM), and fine soil particles to the floodplain, supporting many aquatic organisms. The riparian corridors that line the channel are able to influence light and temperature exposure, regulate labile organic matter falling into the stream in the form of leaves and woody debris, provide vegetative cover and control bank morphology through their complex root system. The alteration of fluvial processes and streamflow has been observed to create watershed-scale changes responsible for 1. sediment accretion on bars and channel edges forming lower and narrower streambanks, 2. disconnection of tributaries and confluences to the main stem, 3. aggradation of tributary channels as they are abandoned by the main river stem, 4. alteration of the pool-to-riffle ratio necessary to support various stages of macrofauna, 5. lack of inundation and nourishment of stream bars, 6. lower water tables that are no longer recharged, and 7. valley floors that no longer receive the nourishment and water supply from the channel (Hill et al. 1991). All these factors in their natural state maintain favorable conditions for riparian habitat, fish community assemblages, and overall stream productivity. Studies have shown that floodplains are highly resilient, and can adapt to altered flows overtime, developing physical features that can balance the effects of reduced flows and sediment inputs. Despite their ability to adapt, the ecological richness and ecosystem services lost to the adjusted flows are significant and difficult to remediate (Hill et al. 1991).

The development of four identifiable flow regimes have been identified: instream flows, channel maintenance flows, riparian maintenance flows, and valley maintenance flows. *Instream flows* are generally considered to be the base-level flow of the stream, present even in the absence of precipitation and sustained by groundwater supply. *Channel maintenance flows* are those consisting of moderately high flows able to carve out invasive vegetation growing into the channel and capable of removing sediments to maintain unobstructed flow passage. Studies have found that an intermediate channel maintenance flow is effective at transmitting the optimal sediment and thus determines the channel physical form. *Riparian maintenance flows* are also referred to as floodplain flows. There are no specific methods to determine the appropriate flow discharge or duration necessary to maintain floodplain integrity in the existing literature. Riparian maintenance flows are generally understood as the peak flows with a capacity to infiltrate the floodplain, reaching certain types of generalist vegetation seeding and growth. *Valley maintenance flows* are determined by climatic conditions, magnitude and frequency of high-flow events, and vegetation quantity. The valley maintenance flows are often the most difficult to assess because valleys are considered legacy features that may have been formed by multiple phenomena, and don't necessarily ascribe to fluvial processes only. Valleys can be formed by glacial activity, geologic faults and lava flows. Moreover, some valley types like, those characterized by wide floodplains, do not depend on the energy of streamflow to maintain their geomorphology, in contrast, streamflow energy, meandering, and scouring depend on the adjacent hardiness of the valley (Hill et al., 1991). Understanding the different types of flows and their unique roles in the health of a channel is necessary to provide streamflow recommendations that protect ecological linkages and their conservation.

Preservation vs Development of Free-Flowing Rivers

The following research by Haynes and Hanley sets out to understand the enduring rivalry between environmental economics and the preservation of the natural environment. The research is based in the Roughty River system in County Kerry of Ireland, where mild and wet climate terrains yield the most productive and high-quality rivers in the world. The conflicting ideologies between freshwater market value and their preservation is a serious concern (Haynes & Hanley, 2006). In this study, an economic estimation is made for the non-market benefits provided by natural river conditions as opposed to artificial impoundment for hydroelectricity.

The ability to determine and assign value to a river network based on ecological and environmental assessments has become a necessity in Ireland, as whitewater sites and recreation compete with an increasing demand for hydroelectricity (Hynes & Hanley, 2006). Hynes and Hanley have made several contributions to river science, including: 1. Estimations of whitewater kayaking demands in Ireland 2. The utilization of these estimates to compare recreational pursuits and hydro-electric schemes. 3. And data collection from online and on-site surveys to eliminate endogenous stratification and bias (Haynes & Hanley, 2006).

The threats to Irish rivers come from many different sources. Some of these sources originate from pollution and water diversions in the name housing development, mining operations, forestry, and are aggravated by nonpoint pollution from agriculture. The stream discharge necessary for whitewater activities is proportional to the elevation gradient and discharge at that site, therefore the simultaneous use of a stream system for hydroelectric damming and whitewater sports is inconceivable. To minimize this interdependency, run-on-the river schemes have become a common approach in Irish rivers. Run-on-the river schemes operate in response to the preexisting conditions of natural channel flow velocity. When flows are low, energy generation is limited, making their implementation reliant on weirs and additional river diversions. These additional structures have lower environmental impact compared to river fragmentation from dams, and therefore their implementation is favored. The Roughty River is one of the many river networks that has fallen victim to this type of approach. These diversions accumulate throughout the system and have compounding effects at large-catchment scales. With multiple weirs and artificial channels within the obstructed river, whitewater recreation is obsolete (Haynes & Hanley, 2006).

Ireland has experienced an exponential demand for electricity in the past decade. To procure this electricity demand, the Alternative Energy Requirement (AER) Programme was introduced. This programme has proposed a series of renewable energy generators with the goal of merchandising energy supplies to the Electricity Supply Board (ESB). Expectations for hydroelectricity generation have increased from 4MW in 1995 to a projected 500MW in 2005, allocated from multiple micro dams. The contrast between dams and whitewater sports is aggravated when we consider that an optimal whitewater trip requires a lengthy stretch of a river providing multiple slopes and rapids schemes, as opposed to a short, high gradient section for a weir to harness flow energy (Haynes & Hanley, 2006). For this reason, the number or Irish rivers suitable for hydro-electric schemes is far greater than for whitewater kayaking. Moreover, the most attractive rivers for energy generation are often those for which whitewater kayaking is ideal. “According to the American Whitewater Organization (AW), “wild river” protection from hydroelectric development is one of the greatest unresolved land management issues in the United States” (Haynes & Hanley, 2006). The organization is responsible to acquire extensive hydrological data for American rivers and provide environmental impact assessment to protect anthropogenic disturbance. Ireland has no such organization and representation for wild river conservation is very limited.

The study found that lower recreational use of the river is proportional to lower flow yields associated to damming operations upstream of the river system. In a river fragmented with weirs and channel diversions, visitors are less likely to pay for the aesthetic and recreational value of the modified river. For this economic reason, it is imperative to set aside many free-flowing river systems to enable economic and recreational growth (Haynes & Hanley, 2006). In the case of the Roughty River, its value is centered around market influence and energy generation and completely neglects the environment and biodiversity richness of the stream. Losses to society from fragmented rivers is proportionate to the loss in scenic value, fishing activities, impacts to endemic vegetation and biota, and even local riparian communities. Limited consideration is given to the whitewater industry and its recreational value within the river system, which from a planning perspective, could serve as useful leverage considering the multiple organizations and alliances led by whitewater enthusiasts in Ireland. Increasing the value of tourism and the whitewater industry is crucial to create awareness and prioritize river conservation from an ecotourism view, favoring the market value of the river scheme and appealing to local governance and developers (Haynes & Hanley, 2006).

Streamflow Supporting Whitewater

The various forms of whitewater boating activities practiced in the United States require unique flow volumes and velocities to maximize user satisfaction. In this paper, Menges and Frey identify the unique streamflow thresholds preferred by different professionals and sportsman for recreational purposes on the Gunnison River of Colorado (Menges & Frey, 2017). The study was implemented in 2013 by the American Whitewater Association in an attempt to formulate data on recreational use particular to the Gunnison River, and contributing to the Colorado River Basin Supply and Demand in educating freshwater conservation. A Basin Implementation Plan for the Gunnison River is proposed in order to assess the recreational potential in the Gunnison River network. A closer look at the relationships between streamflow discharge and recreational quality was obtained through data collection via an online survey. A total of 331 respondents were evaluated and asked to rate streamflow for whitewater boating for each of the 17 stream segments within the Gunnison River basin. The data provided was analyzed to identity streamflow thresholds of minimum, acceptable and optimal flows that enable whitewater boating. The analysis was performed through Flow Evaluation or Impact

Acceptability Curves. These curves describe whitewater "niches" or optimal recreation experiences unique to discharges providing technical boating experience and/or challenging flows (Menges & Frey, 2017). The qualitative and quantitative data were used to evaluate future freshwater risk management for whitewater recreation in the Gunnison Basin.

Whitewater recreational practices are dependent on streamflow characteristics. Lower flows, offer different paddling opportunities and allow for scenic appreciation. As discharge increases from zero, unique flow challenges can range from too low, minimal, acceptable, technical, optimal, high challenge, and too high. According to the survey data collected, the various experiences in flow tend to occur in social "niches". Some flows were favored by canoers but were deemed inefficient for rafters. Different boating craft types displayed niches or preferences for a given set of flows within their boating style. The streamflow or discharge also determined the aesthetic value of the boating trip, with slower flows enabling landscape and scenery appreciation, greater travel times and riverside and camp accessibility while providing safety in the event of rapids. Understanding the dynamism of streamflow in providing optimal conditions for each whitewater boating activity is elemental for the Gunnison River since recreational value accounted for $6,347,748 in economic returns in 2011 alone (Greiner and Warner, 2012). Commercial rafting in the entire state of Colorado supported over 2,600 jobs and provided $54 million in revenue in 2006. At the Colorado Basin scale, recreation activity based on river and streamside activities supported 25,000 jobs and produced $26 billion in economic output (Southwick, 2012).

The Recreational Flow Assessment method utilized in this study based on online surveys provided streamflow categories effective for whitewater and recreational management (Shelby et al. 1992). The survey functioned as a recreation quality evaluation for specific measured flows on each study segment and could be answered in a scale ranging from: unacceptable -2, slightly unacceptable -1, marginal 0, slightly acceptable 1, and acceptable 2. The answers were aggregated to define a minimum and optimal range of acceptable flows reflecting the perceived degree of difficulty, challenge and enjoyment, from lowest to highest preferred flows. It was found that optimal flows provided the most desirable conditions for the highest number of users and their boat craft.

Overall, the Flow Evaluation Curves indicated that minimum acceptable flows for smaller tributaries ranged between 400-800 cubic feet per second (cfs). Minimum flows increased with stream order downstream with higher discharges and velocity (Menges & Frey, 2017). The minimum acceptable flow was described as “the lowest flow you would return to boat in your preferred craft, not the minimum flow that allows you to navigate the section”. Similarly, optimal flow preferences were relative to stream size. Respondents characterized flows beyond the “acceptable” flow range as those in which the paddler would not “make the trip to the river to paddle”. In contrast, the streamflow that fell within the acceptable range were categorized as flows in which as great majority of respondents claimed they “would travel from across the state, and for certain segments, even from around the country to paddle”. The study found that the type of river craft that a respondent used influenced the overall agreement of lower and higher values in cfs of acceptable streamflow (Menges & Frey, 2017).

The ideal flows for the Taylor River of the Colorado Basin, for example, had minimum flows identified by the Impact Acceptability Curve at 400 cfs with a .21 agreement among respondents (79%), qualifying this value as an acceptable flow. At 300 cfs however, responses were at .31 (69%), identifying greater levels of disagreement over its acceptability. The optimal conditions were found to require lower flows than those identified as safest or highest acceptable. Integrating both values allows for a complete assessment concluding that 350 cfs is most likely the lowest threshold of acceptable low flows in the Taylor River.

The optimal flows identified in this study will serve as a management tool for whitewater and recreational activities, enabling streamflow and freshwater planning to cater to the ecotourism industry, maximizing economical value.

Optimal Streamflow for Recreation

This research highlights the role of riparian vegetation along stream channels and its crucial role in maintaining fish populations and the role of fish as a critical food source for birds. Suitable fish habitats are controlled by various physical factors within the stream channel, including depth and velocity, substrate, temperature and quality of water. The successive life stages of fish require unique preferences within these physical factors, creating a viable and complex ecosystem nearly impossible to imitate. Fish habitat quality is supported and often enhanced by the presence of riparian cover, including riparian vegetation, submerged logs and branches, as well as levels of water turbidity (as a response to sedimentation) and water surface opacity, among other characteristics (Mosley, 1983). It was observed in the study that for selective behavioral activities, fish prefer submerged vegetation, for reproductive behaviors in contrast, they tend to select open areas with greater visibility. These curious ecological behaviors have investigated further research by the Instream Flow Group (IFG), creating an incremental method of instream flow assessments that utilizes riparian cover type and density as its main identifiers (Mosley, 1993). These methods will be useful in water resource development to predict potential impact attributed to reduction and homogenization of riparian cover upon bird life in response to changing discharges. The IFG concludes that the possibility to construct habitat suitability curves for birds and fish assemblages alike and expose their dependence on water depth, velocity, substrate, area and other flow-related variables, is facilitated by the study of riparian density. Discharge is a main driver for channel morphology, modifying water surface width, mean depth, and mean velocity. Artificial modifications to a stream channel, including the construction of reservoir or stream diversion, will inarguable influence the natural stream regime, therefore establishing the relationships between instream uses and water discharge is vital (Mosley, 1993).

Humans are directly affected by changes in stream discharge and flood flows. In the Luggate-Queensberry power development on the Clutha River of New Zealand, a rapid increase in discharge resulted in a catastrophic event where recreationists were drowned in their attempt to cross the Clutha River channel. More recently, rafting and canoeing parties have reported rapid rising flows as they have been forced out of the water in the Tongariro and Motu Rivers (Mosley, 1993). Many other reports exist involving hazardous flows, but not all of them have resulted in death, these events rarely make the headlines and awareness remains obscure.

The human hazards inflicted by rapidly rising floods have been studied in detail and a collection of “safe” flows have been recorded. According to an unpublished report on the Motu River it was found that professional rafters considered 350 cubic meters per second at the mouth of the river to be the upper limit for a safe navigation. Records show that during the rising stages of a 2-year flood stream discharge was increased to approximately 780 cubic meters per second in just 2 hours. The Motu River has experienced eight floods within 1960-81, with discharges 50 times greater than the preceding base flow. The Motu River experiences and average of 11.6 floods per year with flows exceeding 350 cubic meters per second at the mouth, and with thousands of people utilizing the Motu River for recreation, it is likely to experience multiple navigational hazards (Mosley, 1993).

CHAPTER III

OUTLINES OF PROCEDURES

Study Area

The study area is located in the VII Region of El Maule in South Central Chile, home to a riverine community at the confluence of the Teno and Claro Rivers known as Los Queñes. The location of the proposed dam retention wall corresponds to the latitude and longitude coordinates of 35°00’02” South, and 070°45’37” West. The analysis of the region was conducted using the Sirgas-Chile Datum, and the projected coordinate system Sirgas_Chile_Zone18S. To understand the topography and environmental profile of the study site, it is beneficial to understand the climate and topography of the Maule region. The following *Table 2* shows geospatial properties of the Maule region including surface area, population and capital city. *Figures 10* and *11* are visual representations of the Maule region within South America and the Mataquito watershed within the Maule region.

Table 2. Geophysical Profile of the Maule Region

VII Region: Maule	
Coordinates	34°41'00", 36°33'00" South, 70°20'00" West
Capital City	Talca
Surface Area (km2)	30,296.10
Surface Area (%)	4% of Continental Chile
Population	1,044,950 (6% of Nat'l population)

The topography The Maule region is limited to the North by the VI Region of Libertador Bernardo O'Higgins, to the East by Argentina, to the South by the VIII Region of Bío Bío, and to the West by the Pacific Ocean. This region has a registered population if 1,044,950 inhabitants and a population density of 30 inhabitants per km^2. The Maule region comprises roughly 6% of the total 17,574,003 census population reported in the 2017 census assessment for Chile ("Censo Chile", 2017). Populations and major cities are centered in the intermediate depression due to high agricultural productivity. These sectors are distinguished by three major complexes: Curicó-Lontué-Molina; Talca-San Clemente-San Javier-Linares and the urban complex of Parral. The heterogeneous topography of the region is characterized by extensive coastal plains, the Cordillera of the Coast, intermediate depression (valley), the precordillera, and the Cordillera of the Andes. The coastal plain extends 5km in width and is delineated to the east (inland) by the Cordillera of the Coast. The Cordillera of the Coast range has a maximum elevation of 838 meters above sea level (m.a.s.l). The valley or intermediate depression can reach widths of 42km and is bordered to the East by the sedimentary precordillera. The precordillera of the Maule Region exhibits elevations between 300-850 m.a.s.l and an average length of 420km. The Cordillera of the Andes is the Easternmost limitation of the region and its range harbors 5 major volcanoes: Descabezado Grande (3,830 m.a.s.l), Descabezado Chico (3,250 m.a.s.l), Quizapu (3,050 m.a.s.l), Cerro Azul (3,810 m.a.s.l) and the currently active Planchon-Peteroa complex (4,090 m.a.s.l), just 26.45km upstream from the proposed dam location. *Figures 13* and *14* provide geospatial context for the Maule region and Mataquito watershed.

Figure 13. Map of South America and the Maule Region

Figure 14. Map of the VII Region of El Maule and the Mataquito Watershed.

The prevailing climate of the region is of Mediterranean nature, with climatic variations associated with the increase of latitude and the elevation variability of the landscape. There are significant climatic differences between the coast, the intermediate depression and the Andes mountain range. In the Andes, high altitude climate predominates creating a tundra-like biome with abundant rainfall and winter snowstorms. Here, precipitation reaches an annual average of 2,000 mm, nourishing the fertile headwaters and floodplains of the Teno and Claro Rivers. *Figure 15* depicts the climatic zones found in the Maule region, and within the Mataquito watershed.

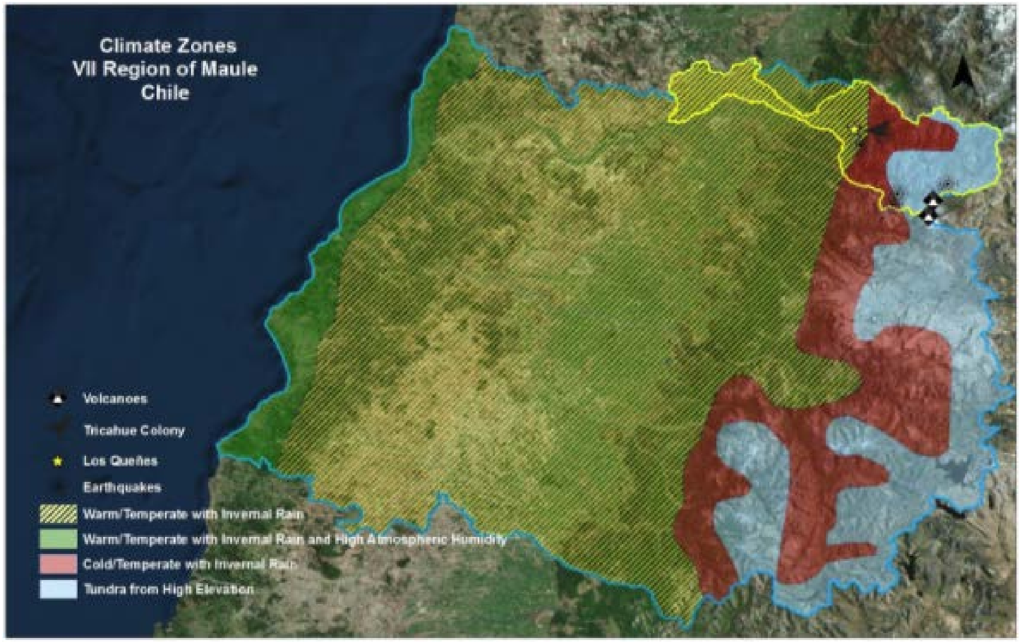

Figure 15. Climatic Zones of the Maule Region and Mataquito Watershed

The hydrography of the Maule region is characterized by a transition from snow-fed headwaters to a combination of snow and pluvial regime as rivers descend, explained by the changing elevation gradient and precipitation patterns from the Cordillera de Los Andes to the Pacific Ocean. The largest rivers that drain this region are the Mataquito and the Maule Rivers. The Mataquito River is formed by the confluence of the Teno and Lontué Rivers and has an average drainage density of 53m^3 / sec, nested in the Mataquito watershed which encompasses 6,050 km^2 and can be visualized in *figure 16.*

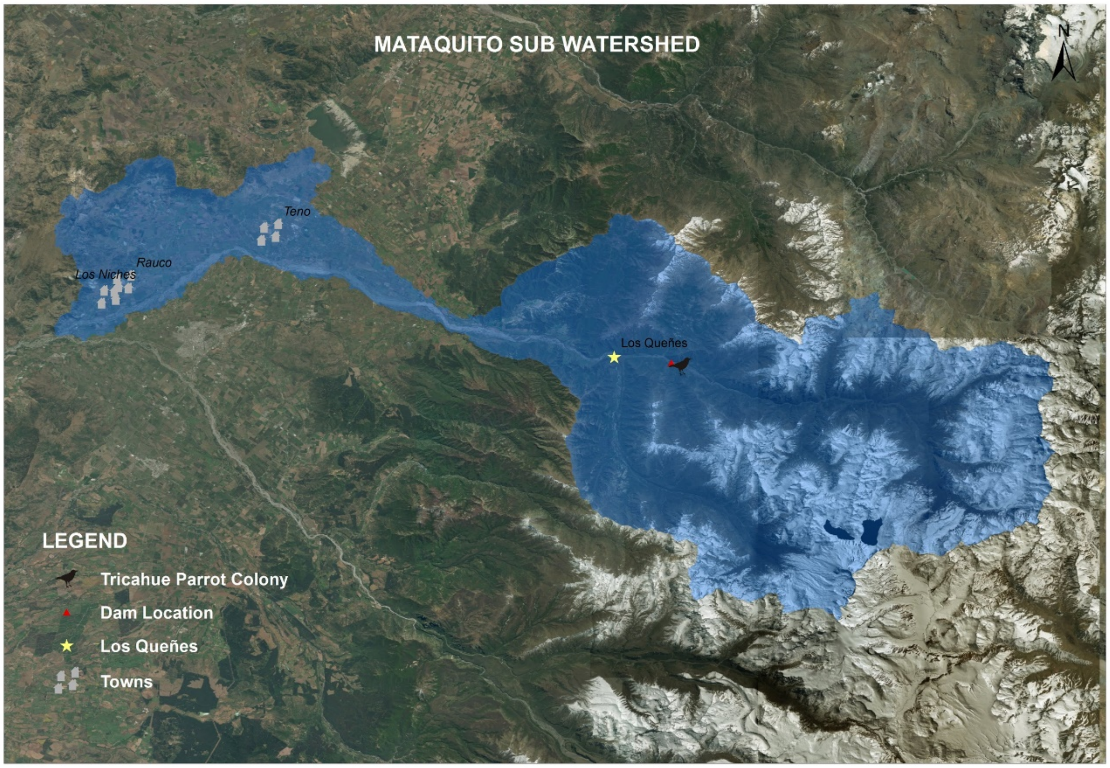

Figure 16. Geophysical Map of the Mataquito Watershed

The ecological risk of a hydro dam in the selected area severely targets an endangered Tricahue Parrot population. The species became legally protected in 1972 under the Supreme Decree N° 40, which indefinitely prohibited the hunting, transportation, commercialization, possession, and industrialization of various species of Chilean birds, including the Tricahue Parrot. In 1996, protection was enforced under law N° 19.473 which prohibited the hunting or capture of the Tricahue Parrot in all of Chile. This law includes the destruction of nests, the gathering of parrot eggs, and the capture of chicks. These legal efforts relieved some ecological pressures, however, they failed to address the threats of illegal commerce or the black market (www.elamaule.cl). In 1982, the National Forestry Corporation (CONAF) initiated the *Project for the Conservation of the Tricahue*, extending from the III region, and skipping over to the VII region, the last two regions where the species remains. During that time, it was estimated that 12 active colonies, and 9 inactive colonies with an average of 1,555 individuals total remained in all of Chile. In response to this ecological disaster, other agencies joined the project, including the Agricultural and Livestock Service (SAG), the Catholic University of Chile, the National Committee for the Defense of Flora and Fauna (CODEFF), among other non-governmental groups and organizations. The groups established educational trainings catered to civilians focusing on rescuing individuals in captivity and victims of illegal trade for further rehabilitation, reproduction and reintroduction into areas of recorded species extinction. This rehabilitation work was parallel to protection efforts in areas where active Tricahue colonies had been reported. These efforts have contributed significant information on the species, both in captivity and semi-captivity, which has helped to understand and protect the remaining wild populations (www.elamaule.cl).

Ecological assessment studies conducted by the Federal Environmental Ministry of Chile (Ministerio de Medio Ambiente del Gobierno de Chile) estimate approximately 1,273 individuals of Tricahue parrots in the Mataquito watershed. The subjects were identified in two colonies: the “Manantiales” colony with 195 estimated parrots, and the “Rio Claro” colony with roughly 877 individuals. The third colony of “La Jaula” is located in the banks of the Teno River along the transect planned to be flooded for reservoir construction. Species sighting was conducted by an authorized member of the

National Free-flowing Rivers Network and estimated approximately 201 individuals. All populations are experiencing population declines since the previous census.

The Teno River's hydrological connectivity is nested within the Mataquito watershed and has a confluence with the Lontué River, forming one of the two major rivers of the Maule region: The Mataquito. The Teno headwaters are located in a lagoon at the foot of the active Planchon-Peteroa Volcano and have previously been dammed in the name of flood control. The river reaches a length of 120km before it reaches the Mataquito River and has an area of 1,590km^2. The average precipitation for the Teno River is 807 mm and an average annual temperature of 12.8 degrees Celsius. The banks of the river in the area of study are composed mainly of limestone and sandstone, creating the perfect habitat for the burrowing Tricahue parrot. Optimal whitewater rafting flows occur in spring/summer (with the melting of the snow) with a broad range of 500 to 3,000 cubic feet per second (cfs) (http://riversofchile.com/rio-Teno). *Table 3* offers a hydrological profile of the Teno River. *Figure 17* shows the confluence of the Teno River (reddish-brown) and the Claro River at the Southernmost limit of Los Queñes.

Table 3. Hydrological Data for the Teno River.

Teno River Profile	
Length (Km)	120
Area (Km2)	1,590
Drainage Area (m3/s)	42.4
Avg. Annual PP (mm)	807
Avg. Temperature (°C)	12.8

Figure 17. Confluence of the Teno and Claro Rivers. Photo by Dominique Haller

Methodology

Data Acquisition

The data and documentation from scholarly and peer reviewed articles provided extensive information at the watershed and river scale of hydropower implementation. Ecological data was acquired from the World Wildlife Organization, the IUCN Red List database, CONAF (National Forestry Corporation), Ebird Chile, Department of Agriculture, The Environmental Ministry of Chile, animal sightigs and location data provided by an authorized member of the Free-Flowing Rivers network. These data were used to identify relationships between the endemic endangered species of the Tricahue Parrot and the unique geographical characteristics of their limited biogeography within the Teno River and Mataquito watershed.

Digital elevation models (DEM) were downloaded from ASTER GLOBAL DEM database through the USGS Earth Explorer website and further mosaicked in a GIS to provide a topographic depiction of the area of study and a raster basis for watershed analysis. In further accounting for endangered species, home ranges were depicted on the DEM to visualize and stress the importance of an intact natural system. A GIS served to procure cartographic imagery of the ecological, environmental and recreational components respective to the local biodiversity and its community.

Tourist expenditure data were acquired from the Office of Tourism and National Tourism Service. The tourist expenditure data was compiled as a joined effort from the Studies Division and the Statistics Department, yielding a technical report utilized for this study. The report synthesizes the information acquired by the Monthly Survey of

Tourism (Encuesta Mensual de Alojamiento Turístico [EMAT]) and was further analyzed by the National Institute of Statistics (INE). Additional tourism values were measured in US dollars and refer to specific daily rafting and kayaking trips for the Teno and Claro Rivers of Los Queñes. The data were obtained from individual online surveys directed to two whitewater companies and a camping site owner, of whom personal identification were kept confidential and referred to as "Whitewater Company A", "Whitewater Company B" and "Camping Site". These entities provided tourism values for average daily trips and daily trips during high peak season, as well as estimates of total clients requesting their services. Additional information was provided on rafting and kayaking rates expressed in Chilean Pesos. These values were converted into US Dollars for the purpose of this study.

Creating and Projecting DEM

Modeling of the reservoir was performed using a GIS. The geospatial data layers were visualized in a 3D environment provided by ArcScene. Individual digital elevation models (DEMs) were acquired from ASTER GLOBAL DATA through Earth Explorer at a spatial resolution of ~ 30 meters. Each DEM was combined to create one mosaic or composite raster DEM with continuous elevation data values. The composite was created by selecting one individual DEM layer as a target DEM whose spatial properties would be preserved and interpolated unto the rest. The composite raster DEM was projected onto the *Universal Transverse Mercator* (UTM) map projection for South America, and later referenced onto Chile SIRGAS Zone 18 projected coordinate system under the name *StudyAreaChile*. *Figure 18* shows the projected DEM (*StudyAreaChile*).

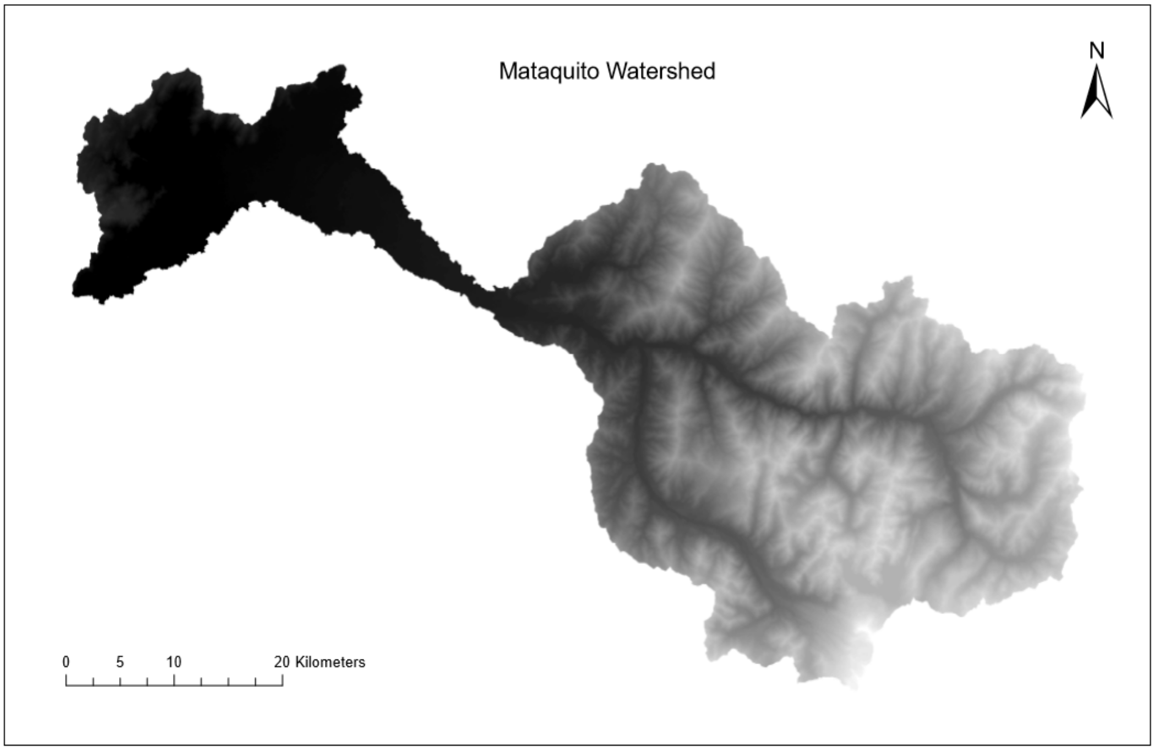

Figure 18. Digital Elevation Model for the Mataquito Watershed

Spatial Analysis: Delineating the watershed

Watershed delineation was performed to identify the surface-water runoff influence unique to the Teno River and its tributaries, producing a detailed boundary of the drainage divide composing the hydrological network unique to the Teno River. The raster on which hydrological spatial analysis was performed was the *StudyAreaChile* DEM previously created. Watershed delineation requires a DEM without any "sinks" or depressions. These sinks may cause errors in the resolution of the elevation data. The presence of sinks in a DEM may occur when all the connected sink cells are either higher than the processing cell, or when these cells flow into each other, prompting a two-celled loop (Jenson, 1991). After sinks were identified in the DEM, an output raster was generated designating the sink values from one to the total number of sinks present. The more sinks present in a DEM, the longer the processing time will be. After all sinks were identified for the *StudyAreaChile* DEM, sinks were filled to ensure proper delineation of basins and streams. The process of removing all sinks required the iteration of an algorithm that detected and filled all sinks. *Figure 19* depicts the process of filling a sink. Upon filling sinks, other sinks were created. These additional sinks were removed until the DEM was void of all previously defined sinks.

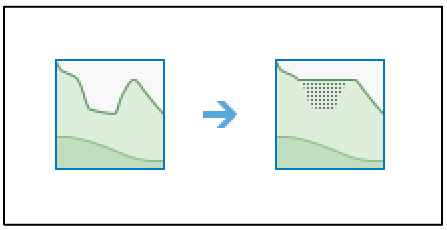

Figure 19. Hydrological "Sink" Method

A filled DEM will ensure accurate resolution and remove minor imperfections in the elevation raster. Upon creating an output DEM with filled sinks, further analysis was conducted to determine the flow direction of water. This process identified the direction of flowing water from one cell to its nearest downslope neighbor and its orientation was assigned a value ranging from 1 to 255 respective to a direction. *Figure 20* shows the processing cell (blue) and the adjacent neighbor cell with their respective flow direction identifier number. If the immediate lowest elevation cell was to the left of the processing cell, the flow direction would be coded as 16. If a processing cell was lowest than its neighbors, the cell would have been assigned the elevation value of the lowest neighbor cell and flow direction would be reverted to that cell.

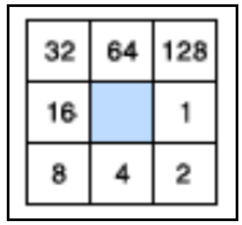

Figure 20. Hydrological "Flow Direction" Method

Flow direction is necessary to estimate the overall accumulation of flow directed into each raster cell (O'Callaghan & Mark, 1984). Flow accumulation shows the accumulated weight of flow into a lowest elevation point and does not consider the value of the processing cell. The output raster for the flow accumulation process yielded cells with high flow accumulation or concentrated flow that were used to identify the entire hydrological network. Inversely, cells with values of flow accumulation of zero were identified as ridges or high elevation areas.

Structure query language (SQL) can be used to manipulate the elevation data and perform conditional statements (true or false) on each of the input cells. A logical expression, for example, can be created to identify whether a certain cell has more than a given number of accumulated flow discharging into it. For this analysis, the conditional statement Value > 25,000 identified all cells that had at least 25,000 other cells flowing into it. When a cell was evaluated as true, this meant that the cell had at least 25,000 cells of accumulated flow going into it, and the cell was assigned a value of 1. All other cells that did not meet the conditional statement received values other than 1. The flow accumulation output created was used to create a stream link raster.

A stream link raster helped to identify and assign unique values to the stream intersections within the previously defined network of accumulated flow. These links represent sections of the stream channel that connect successive junctions, a junction and an outlet, or a junction and the drainage divide. The computed stream link raster delineated the entire hydrological network within the watershed (Lindsay, 2006). The watershed delineation was generated by determining the contributing area of flow above a set of cells in the raster DEM. *Figure 21* illustrates the procedure underlying watershed delineation.

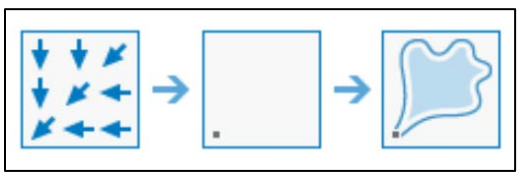

Figure 21. Hydrological "Watershed" Method

Upon delineating the watershed area within the Maule region, the watershed or catchment contributing flow to the Teno River was identified as the Mataquito watershed. The Mataquito watershed was converted into a polygon and used hereafter as mask for future raster analysis. All geo-processes were limited to the Mataquito watershed to promote faster and specific analysis of the study area.

Raster to Triangulated Irregular Network (TIN) Modeling

The digital elevation model previously delineated for the Mataquito watershed was converted into a Triangulated Irregular Network (TIN) surface to enable a three-dimensional visualization of the study area, with an elevation contour difference of 100m. The TIN model served to identify the opposite river terraces where the dam would be located by facilitating the visualization of elevation gradients.

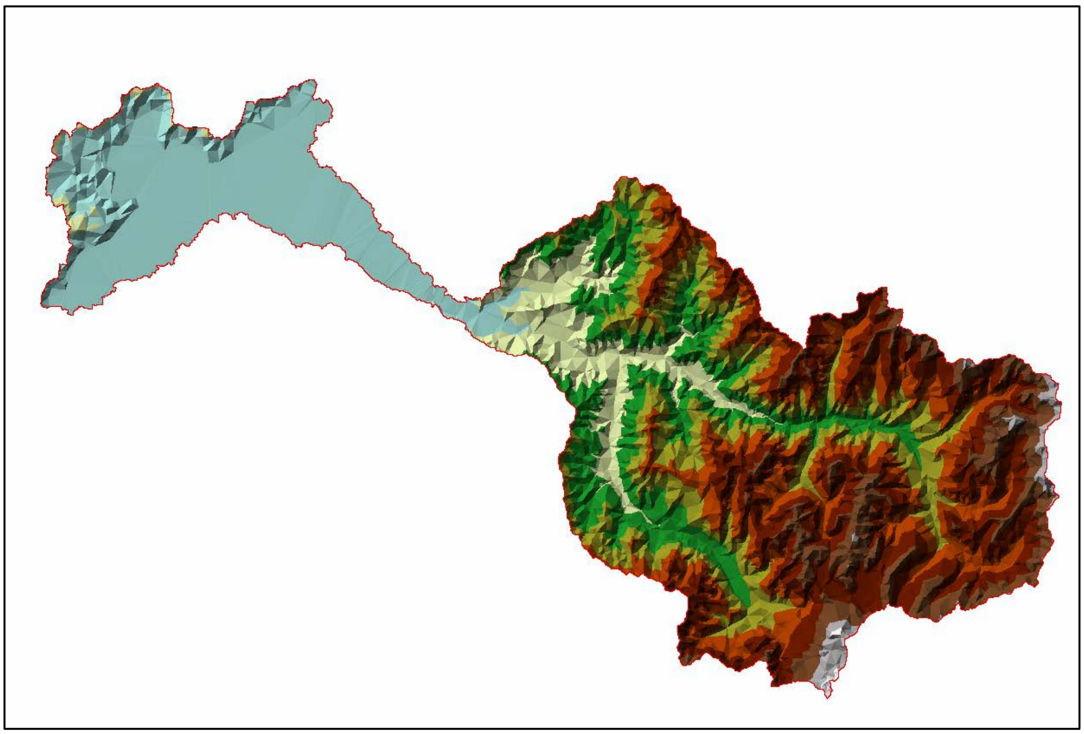

Figure 22. Triangulated Irregular Network Elevation (TIN) Surface of Study Area

Modeling the Dam

The dimensions of the dam used for the purpose of the study represent a minimum approximation of the hydroelectric dam damage potential. The dimensions acquired for the dam correspond to a 110m elevation retention wall, 10m distance between the upstream wall and the downstream wall (crest). The heel of the dam was located at 310m upstream to ensure gravitational safety, and the toe of the dam was located at 300m downstream from the downstream facing wall.

The modeling of the proposed hydroelectric dam was performed using the TIN data model. A new feature class was created as a polyline and edited to digitize an individual transverse line extending across opposite river terraces where the hydroelectric reservoir would be located. The line was copied as a parallel 10 meters to the right to represent the crest of the dam and was assigned an elevation of 830m above mean sea level (msl). This elevation was chosen to reflect the expected height of the dam of 110m and accounted for a ground elevation at the site of 720m. Additional parallels were copied to the right (upstream) at 310m from the original retention wall line and assigned an elevation of 680m. This line represented the heel of the dam. Similarly, another parallel was copied at 300m to the left of the original retention wall line (downstream) and assigned an elevation of 680m. This line represented the toe of the dam. *Figure 23* depicts the anatomy of the proposed hydroelectric dam.

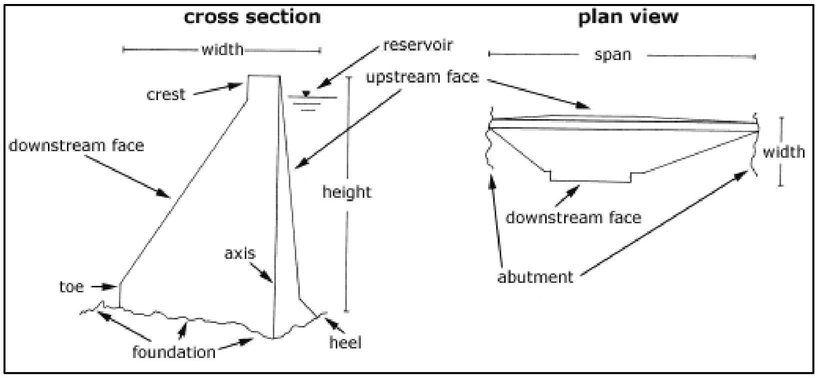

Figure 23. Anatomy of the Dam

After assigning proper elevations to each of the dam lines within the dam feature class, the feature class was converted into a TIN surface to visualize the three-dimensional nature of the dam (*damtin*). *Figure 24* represents the TIN of the dam (*damtin*) as it is superimposed over the study area.

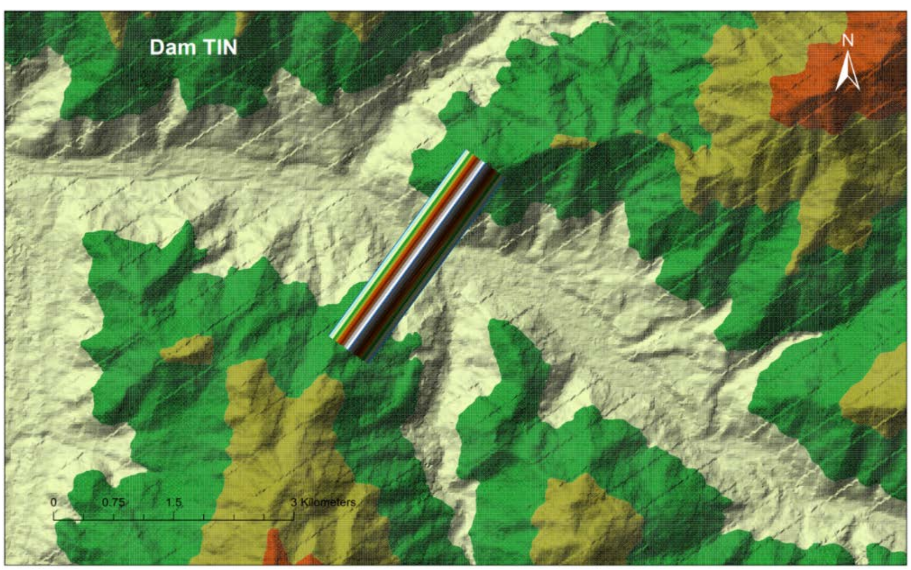

Figure 24. TIN of the Dam Structure

An additional feature class was created as a polyline to represent the water impoundment upstream from the dam. Thirty-six parallel lines were digitized onto the surface TIN and assigned a value of 820m to depict the surface area of the reservoir and to create the volume for the maximum capacity of the dam. This value was determined assuming a safety water threshold that would not exceed 10m from the dam crest (830m). The first parallel was digitized to align precisely with the upstream crest line, and all other lines were digitized to the right of the first parallel, moving upstream. Once these contour lines were digitized and assigned elevations, the feature class was converted into a flat TIN surface (*containmenttin*). *Figure 26* depicts the parallel lines and the elevation compared to the damn. *Figure 27* and *28* shows the TIN of the dam in ArcScene three-dimensional environment.

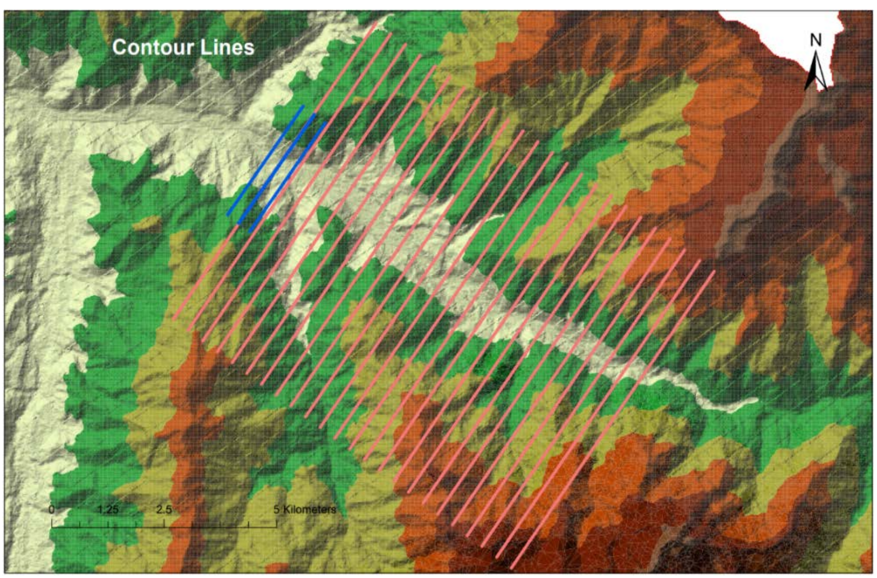

Figure 25. Digitizing Contour Lines for Reservoir Plane

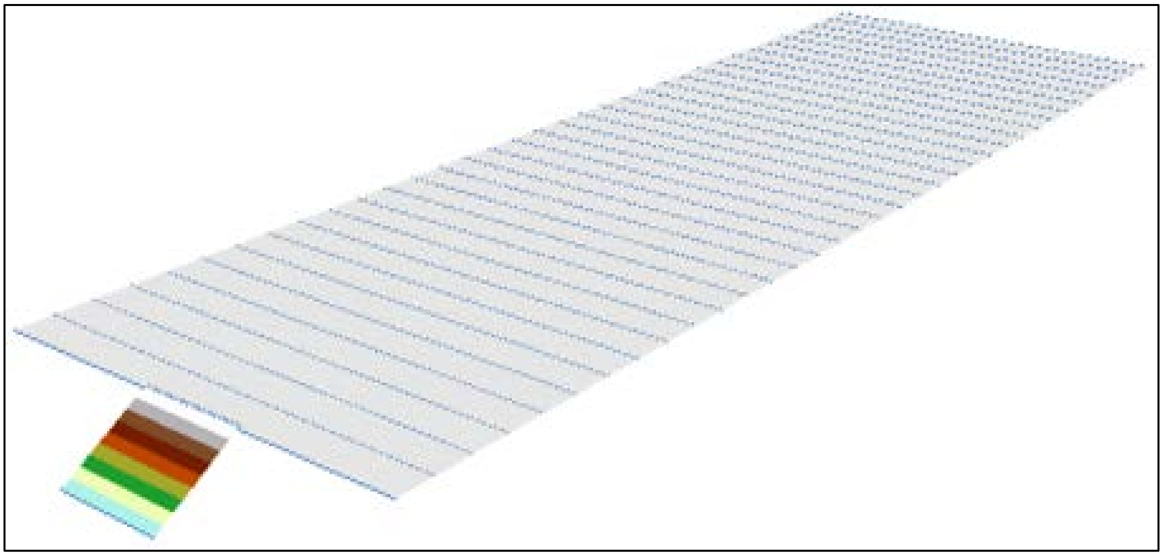

Figure 26. Contour Lines and Reservoir Plane Visualized on ArcScene

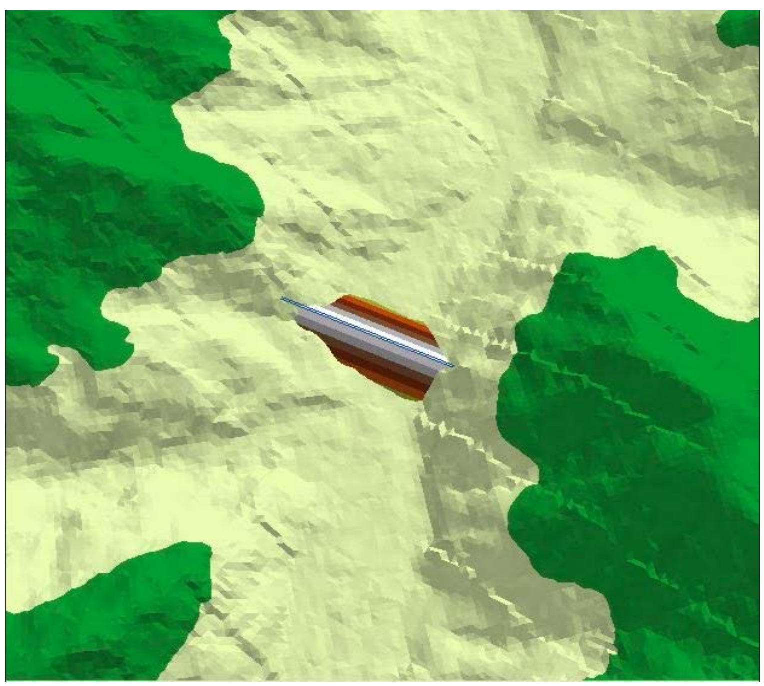

Figure 27. Dam TIN Viewed from Above

Figure 28. Dam TIN Downstream View

Upon creating the (*damtin*) and *(containmenttin*), map algebra was applied to obtain a polygon representing the reservoir upstream from the crest of the dam. This was done by subtracting the elevation TIN from the (*containementtin*). The surface difference operation created a polygon representing the reservoir with a water level of 820m of elevation. The resulting reservoir polygon feature class was edited to eliminate all elevation values falling outside of the 820m elevation threshold. *Figure 29* shows the reservoir polygon containing only elevation values of 820m.

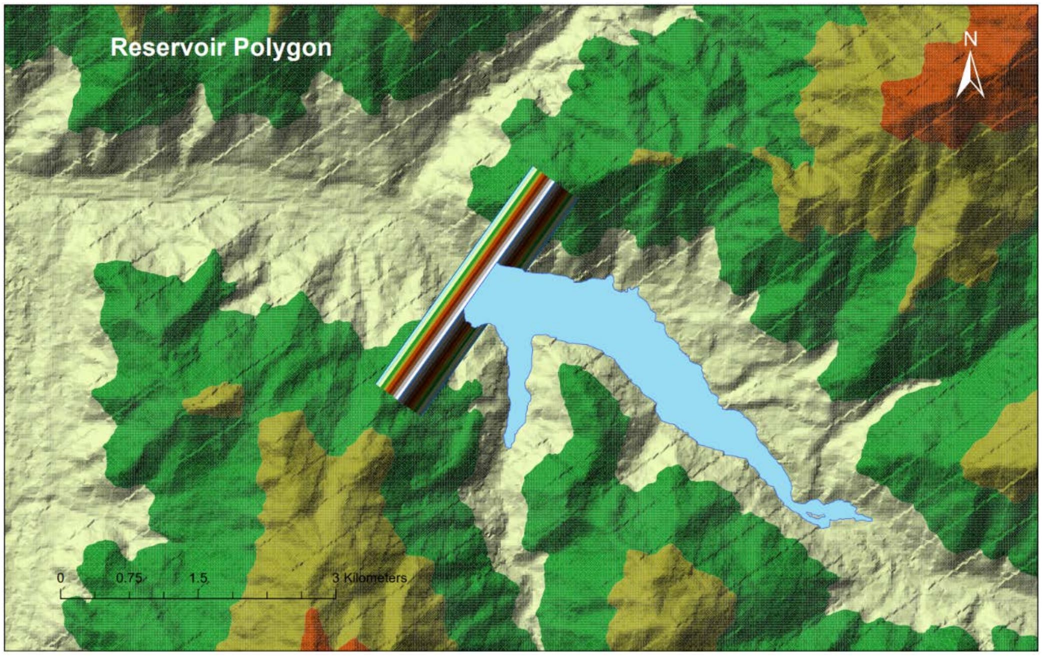

Figure 29. Reservoir Polygon Including Elevations of 820m and Lower

A TIN representing the reservoir polygon and its associated volume and surface area was created to include everything below the 820m elevation threshold, including the slope of the upstream face of the dam. This was achieved by converting the reservoir polygon to a raster with a value of 1 inside and no data outside of the reservoir polygon. The geo-processing environment was manipulated so that the extent, grid cell size, and snap raster were the same as the original DEM (*StudyAreaChile*). The output reservoir raster layer was then multiplied by the original DEM (*StudyAreaChile*) to generate an output raster for elevation values within the 820m contour (*rasterelevations*) using the raster calculator tool.

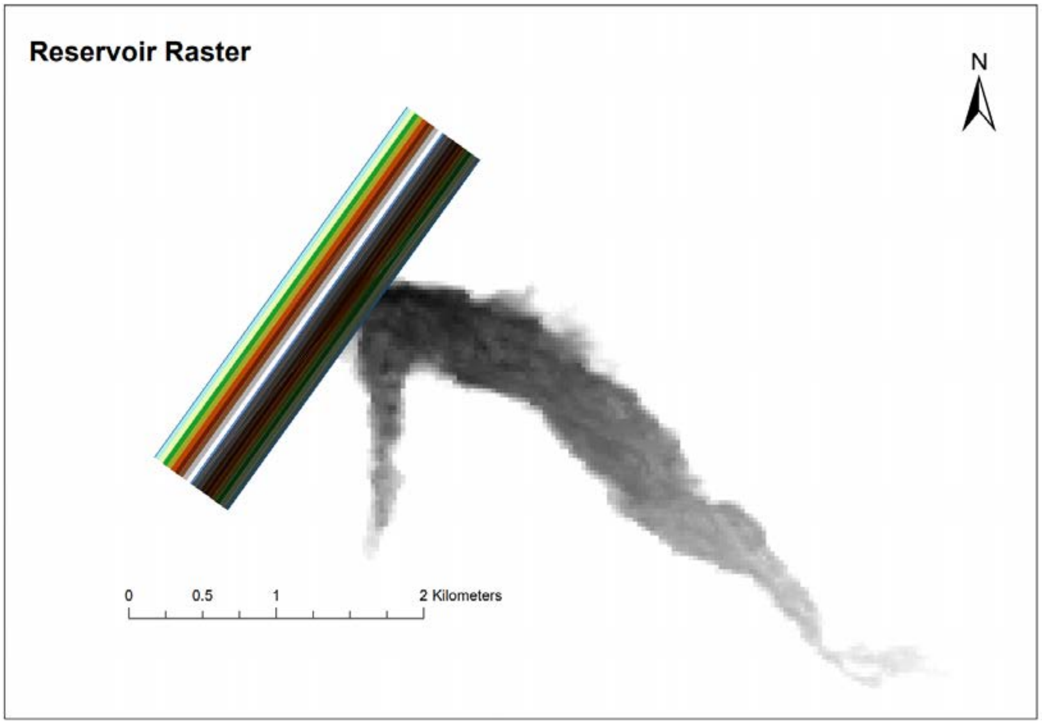

Figure 30. Reservoir Raster

The next step involved converting the new raster (*rasterelevations*) into feature points (*rasterpointelevations*). These points contained accurate elevation values, except for those points intersecting the dam footprint (*dampolygon*) because these points were based on the original DEM (*StudyAreaChile*). In order to correct for this, spatial features were selected by location and all points that did not intersect the new dam footprint were extracted (*reservoirpointelevationsnoddam*). The select by attribute process was repeated and inverted to extract all points from the raster *(reservoirpointelevations*) that intersected the dam footprint and converted them into a new feature class (*dampoints*). The elevation values respective to the new feature class (*dampoints*) correspond to the ground elevation. To correct for this, elevation values were interpolated so that the elevation values in the feature class (*dampoints*) resemble those of the 820m dam TIN (*damtin*). Finally, a TIN surface for the whole reservoir (*reservoirtin*) was generated from the dam points elevation and the reservoir elevation data, depicted in *Figure 31*.

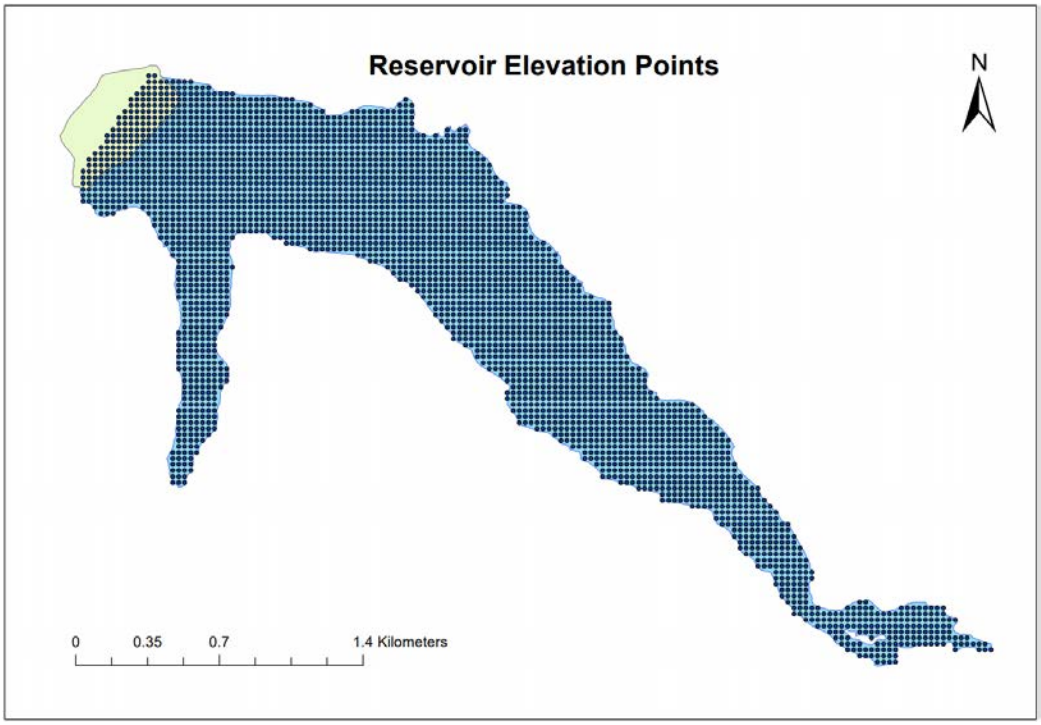

Figure 31. Reservoir Elevation Points

<u>Results</u>

Environmental Impact

The environmental implications of building a 110m tall hydroelectric dam in the selected river transect will have multiple consequences. According to the projected flooded area, a total of 3,966,873 m^2, or 3.97 km^2 will be underwater. The floodplain, riparian corridors and in-stream habitat downstream from the dam wall will be severely degraded. The mechanical and reduced outflow coming from the dam will fail to mimic the natural stream dynamics of the Teno River. The average temperature of the Teno River of 12.8°C is able to sustain multiple organisms vital to the ecological integrity of the river. The natural thermal fluctuations of the Teno are symbolic in the support of benthic and fish assemblage characteristics of the area, including abundant yields of rainbow trout. These organisms are fundamental blocks within the trophic levels and support avian communities and other biodiversity while regulating populations and supporting the river continuum. The presence of the dam and controlled outflow will change the magnitude and frequency of the streamflow and will completely eliminate the recurrence of vital flooding events necessary to nourish the adjacent floodplains and recharge underground water supplies. The sediment load characteristic of high mountain streams such as the Teno River rely on a diverse load of sediment sizes ranging from fine grain materials, medium or gravel-like and coarse particles, including labile organic matter from vegetation, for the formation of periphyton stocks and suitable in-stream habitats. The controlled outflow will produce a caudal with contrasting levels of organic matter, available oxygen and minerals. The sediment particles necessary for channel formative processes of weathering and aggradation will be absent and only a few fine particles might successfully be released downstream. The stratified thermocline within the reservoir will release flows with fluctuating temperatures, making it difficult for resilient organisms to adapt to a drastically changing thermal profile.

In the event of structure collapse or fracture - highly likely in this area given the legacy of volcanism and geological instability- a total of 229,612,176,263 billion m^3 of water would be released at various velocities. The ramifications of such an event will certainly reach the local community of Los Queñes at merely 4.3km downstream of the collapse. The village will suffer severe infrastructure loss from flooding, possible slope failures, and the inhabitants will not have enough time to flee their homes, risking the lives of over 270 locals in addition to tourists and farming animals (Singh, 2013).

Ecological Impact

The biogeography of the *Cyanoliseus patagonus bloxami* subspecies is the smallest of the four-identified subspecies and is only found in Chile. Two disjunct populations are found in the III region of La Serena and the VII region of el Maule. The Tricahue habitats corresponding to the Chilean side are rapidly degrading and the parrot populations are dwindling due to urban development, illegal hunting, and their persecution as pests. Despite national conservation efforts, their protection is limited, and their habitats continue to degrade. Their avian integrity is of utmost importance and must be prioritized. The spatial analysis shows that the reservoir will flood the nesting grounds of the Tricahue Parrot colonies in “La Jaula”, forcing the displacement of the bird, drowning those individuals with restricted movement, as well as any clutches left in the burrows (*Figure 32).*

Figure 32. Biogeography of the Tricahue Parrot Subspecies

This presents an ecological disaster that could be avoided by removing any threats from damming. According to national law N° 19.473, the destruction of the endangered Tricahue nesting grounds is prohibited by federal law. The displacement and certain destruction of the “La Jaula” colony nesting grounds induced by reservoir flooding violates this law and renders the dam as a destructive and menacing operation. Environmental threats that can be mitigated or avoided should be litigated. The construction of a reservoir on the protected premises of the Tricahue colony at risk in Los Queñes needs to be addressed.

Recreational Impact

According to the International Monetary Fund (IMF) Chile ranks as one of the highest gross income per capita (GDP) in the world (5th place) and has the highest ranking in South America, *Table 4.*

Table 4. Gross Domestic Product (GDP) Rankings for South America

South America Rank	World Rank	Nation	2016 GDP (IMF) per capita	World Rank	Country	2016 GDP (PPP) Billions of USD
1	55	Chile	$23,969	8	Brazil	3,081
2	59	Uruguay	$21,570	27	Argentina	879.4
3	61	Argentina	$20,170	32	Colombia	688
4	74	Brazil	$15,211	42	Venezuela	468.6
5	86	Suriname	$15,179	45	Chile	436.1
6	71	Venezuela	$15,102	48	Peru	410.4
7	82	Colombia	$14,161	66	Ecuador	182.4
8	83	Peru	$13,018	94	Bolivia	78.35
9	91	Ecuador	$11,036	96	Uruguay	73.25
10	110	Paraguay	$9,353	103	Paraguay	64.67
11	96	Guyana	$7,919	162	Suriname	8.547
12	118	Bolivia	$7,190	169	Guyana	6.093

It is no surprise that as the economy of Chile continues to grow, tourism market and development is at its peak. In the recent decades, Chile has reported a tourism growth of 12%, increasing from 1.4 million tourists in 2002 to 2.6 million in 2006. The exponential economic growth can be tied to the significant increase in international tourism, although economic evaluations have yet to identify the exact contribution from the tourism sector. This idea is supported by the Central Bank from economic data acquired for the time period of 1988-2008 where tourism increases coincided with national economic growth, concluding that tourism is an important economic driver and employment resource. The development of the tourism industry in Chile calls for stricter environmental laws that ensure the protection of the landscapes and natural resources it relies on. This area has incredible potential not just for attracting international tourists but for expanding tourism areas into other local hotspots, integrating the national population and nearby locals. Domestic tourism is in its early developmental stages in Chile and the industry promises the decentralization of tourism while promoting job creation and entrepreneurial incentive in the areas of lodging and restaurant industry.

The Maule region is a significant area for tourism. The average tourist overnight stay for the Maule region corresponds to 284,526 nights in a year (365 days), ranking higher than the Atacama Desert, and the Southern fjord territory of Magallanes, where the biosphere reserve and renown site of Torres del Paine is located. According to the values on *Table 5*, a total of 6.9% of the country's overall tourist overnight stays was allocated to the Maule region

Table 5. Most Visited Regions in Chile Rankings

Most Visited Regions	Overnight Stays
Metropolitana	6,645,585
Biobío	768,483
Valparaíso	712,170
Antofagasta	533,584
O'Higgins	391,394
Los Lagos	371,681
Coquimbo	314,112
La Araucanía	294,546
Maule	294,526
Atacama	201,032
Tarapacá	172,932
Los Ríos	146,210
Magallanes y La Antártica	124,105
Aysén	99,086
Arica y Parinacota	98,718

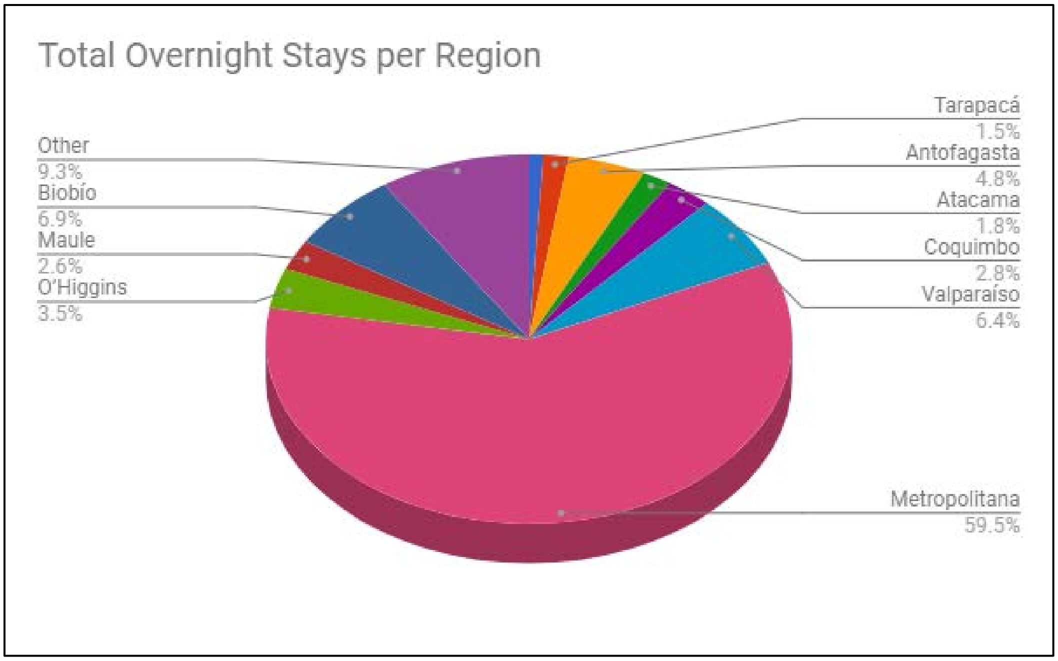

Figure 33. Overnight Stay Data for the 10 Most Visited Regions in Chile

The Maule region is divided into three geographical tourist destinations outlined in the following *Table 6*, with Los Queñes falling into the "Rest of the Region" category. Values for the Maule region show that the destination labelled as "Rest of the Region" was the most visited. These values enforce the belief that economic growth can be attained by a development of tourism infrastructure and amenities, which can potentially be a powerful source of employment for the local population. Proper development of domestic tourism in the *Rest of the Region* area could be highly beneficial for the local communities and may instigate a greater motive for the conservation and protection of freshwater sources, biodiversity, and the identity of the place, relying on free-flowing rivers.

Table 6. Popular Destinations within the Maule Region.

Destination		
Talca and Maule Valley	**Maule Coast**	**Rest of the Region**
Talca	Pelluhue	Colbún
San Clemente	Constitución	Linares
San Javier	Vichuquén	Parral
Maule	Chanco	Cauquenes
Pencahue	Curepto	**Romeral/ Los Queñes**
		Villa Alegre
		Molina
		San Rafael
		Teno
		Pelarco
		Yerbas Buenas
		Rauco
		Longaví
		Sagrada Familia
		Empedrado
		Hualañé
		Retiro
		Río Claro

Arrivals per destination unique to "Rest of the Region" category were significantly higher compared to both Valley and Coastal destinations within the Maule region. Similar results were found for tourism assessment based on annual overnight stay values. This could be due to the invaluable presence of the Andes Mountains, the largest mountain range in all of South America, its ecological richness, freshwater supply and fertility of the valley below.

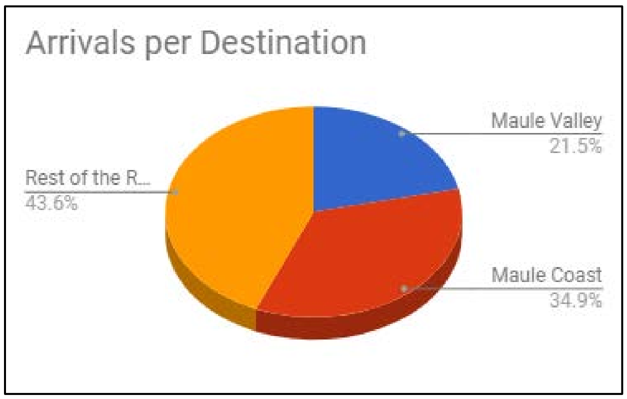

Figure 34. Graph of Arrivals per Destination in the Maule Region

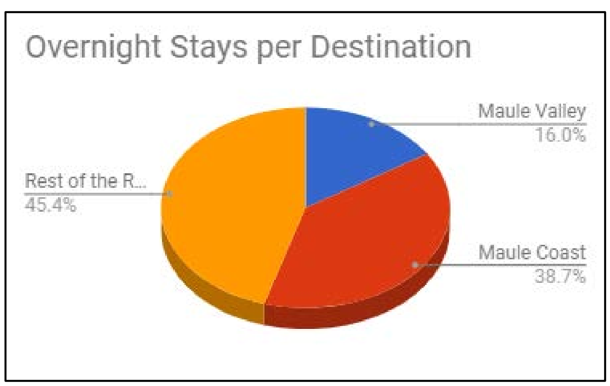

Figure 35. Graph of Overnight Stays in the Maule Region

Tourism data respective to Los Queñes was acquired for the months of September- mid-February given that these months are the peak months for tourism in the form of outdoor recreation and whitewater activities. “Whitewater Company A” reported an average of six daily trips accounting for 20-25 monthly trips. The tariffs for the company were: half day trips at $35USD and full day trips at $70USD. Approximately 605 river users were reported translating into $21,175.00- 42,350.00 US dollars assuming a capacity of 5-6 people per raft including the guide. These amounts exclude lodging, food and drink, souvenirs, and other activities provided by the company such as trekking, mountain biking, pool and artisanal hot tub access, among other services. Similarly, “Whitewater Company B” reported an average of six daily trips accounting for 20-25 monthly trips with slightly different tariffs not provided but interpolated from Company A values. Approximately 864 river users were reported translating into $30,240.00- 60,480.00 US dollars. These amounts exclude lodging, food and drink, souvenirs, and other activities provided by the company
such as zip lining, trekking, mountain biking, pool and artisanal hot tub access, among other services. The camping site has a capacity of approximately 200 people and remained at full capacity during the summer months of December, January and February. Table 7 shows estimated values for total revenue for all three entities were $80,193.50, $102,540.50, and $40,000 respectively.

The economic contribution from the tourism sector analyzed for this study represent but a sliver of the entire tourism framework operating in this location. It does not take into account the median and average income of Los Queñes, creating an exciting venue for further research. Additionally, the value of tourism is largely enforced when considering the multiplier effect governing the industry. The foreign population of tourists visiting the area year-long sustain the entire community of Los Queñes. Although the whitewater companies may exhibit a centralization of wealth, their operation is vital to maintaining other industries alive, such as the food and wildlife appreciation sectors, whether it be through direct employment or indirect trickle-down economics. Taking out the major sustenance of economic health of the area by removing the productivity of its rivers, renders the entire economy and the community itself obsolete.

Table 7. River Based Recreation in Los Queñes

River-Based Recreation/Tourism High Peak Season: September-February 2018			
Activity	**WhiteWater Co. A**	**WhiteWater Co. B**	**Camping Site A**
Weekly Whitewater OR Camping Trips	5 ~ 7	5 ~ 7	-
Monthly Whitewater OR Camping Trips	20 ~ 25	20 ~ 25	-
Total Customers/Guests	**605**	**864**	**950-1050**
Average Revenue from Visit OR Overnight Stay	$45,193.50	$64,540.50	$28,000
Revenue from Rentals, Services, Misc.	$35,000.00	$38,000.00	$12,000
Total Revenue (including other services)	**$80,193.50**	**$102,540.50**	**$40,000**

Tourism in the form of Whitewater activities is a vital component of the Maule region of Chile. Literature shows that the streamflow qualities that favor recreational boating activities and support safe hydrological conditions are specific to the boating craft. These values range from flows that enable scenery appreciation, to challenging rapids that support kayaking and rafting trips. Flow Evaluation Curves generated from online and on-site surveys directed at recreational river users, determined optimal flows for whitewater rafting ranging from 400 to 800 cfs. These flows were described as being worth the cross-country and/or regional travel to enjoy the stream segments. The quantification of optimal recreational flows identified in the literature coincide with the average annual discharge of 500 to 3000 cfs unique to the Teno River, solidifying its hydrological network as a highly valued recreational amenity. Most importantly, research shows that optimal boating activities, which are a fundamental tourism contributor to the Los Queñes community, cannot be supported a par with hydroelectric schemes. Research shows that communities worldwide have been forced to choose between the two, and those communities lacking environmental policies and river enthusiasts are often displaced and undermined by international hydroelectric development. *Figure 36 a* and *b* show Google Earth representations of the study site and the proposed reservoir.

Figure 36a. Google Earth Image Representing the Reservoir and Study Site

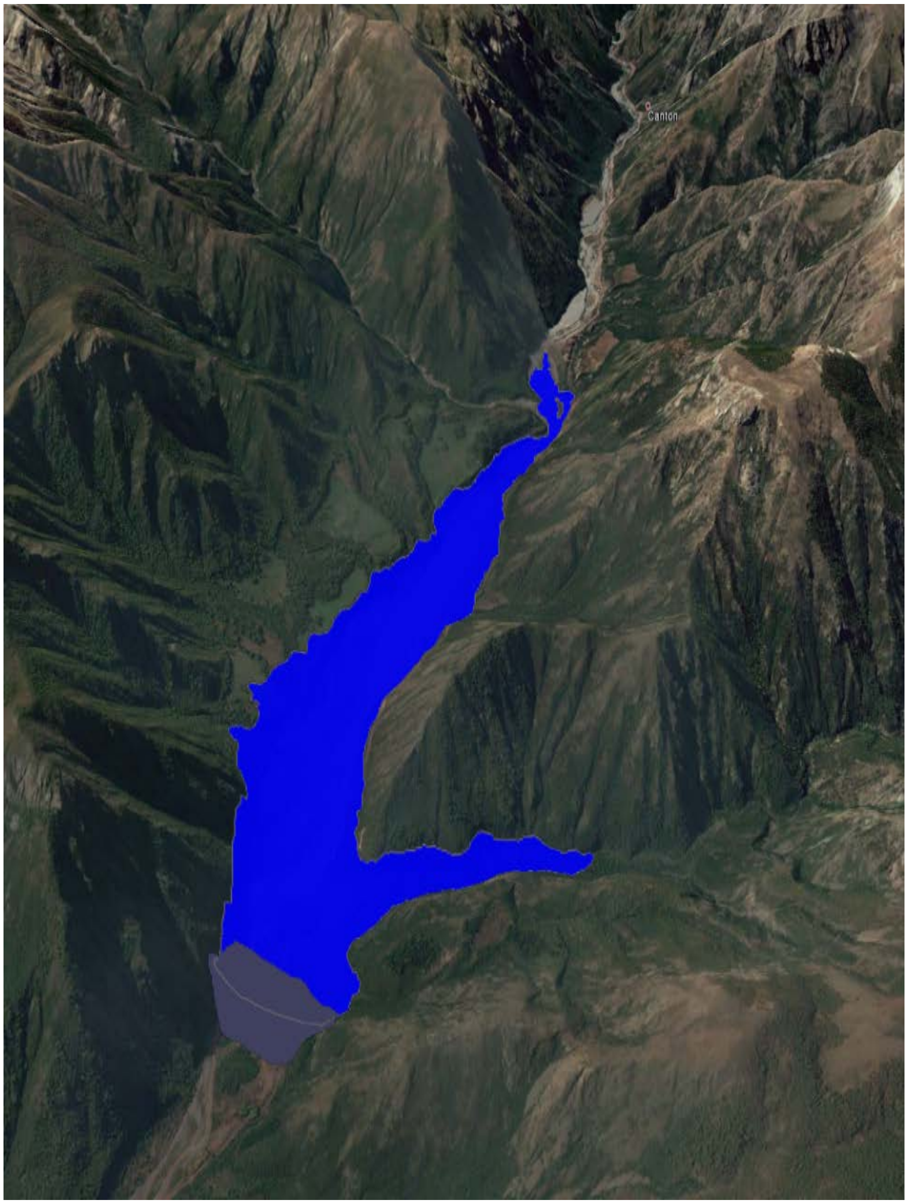

Figure 36b. Google Earth Image Representing the Reservoir and Study Site

CHAPTER IV

CONCLUSIONS

General Conclusions

The need to reduce GHG emissions to mitigate the ongoing effects of climate change is a global ambition. Phasing out current energy production dependent on fossil fuels is a challenging task and procures the development of renewable and alternative forms of energy production. Consequently, the benefit of utilizing water impoundments as viable sources of energy generation is a tangible approach given the availability of freshwater ecosystems worldwide. These freshwater networks are associated to developing countries with emerging economies, growing populations, and extensive natural reserves. These communities do not always have the legal support and the environmental education to assess risks to their communities and their waterways from hydroelectric damming operations. Informing and protecting these valuable communities and the biodiversity within their watersheds is of utmost importance, and this task is underway. The National Network for Free-Flowing Rivers in Chile is a great example of an alliance composed of many different NGOs, scientific professionals, paralegals and knowledgeable communities fighting to protect and amplify the voice of their rivers. Having a connected framework of grassroots activism has brought about important victories for the Chilean people in their efforts to evade river fragmentation from hydroelectric development.

The initial hypothesis developed for the study are supported in the literature review and through geospatial analysis of the study location. The presence of a reservoir located in the selected transect of the Teno River will inundate 3,966.873 m^2, exposing mountainous terrain to the fluctuating levels of reservoir water, debilitating and weakening cliff sides causing slope failure. The seismic and volcanic activity characteristic of the region is alarming, especially considering the number of epicenters occurred within a 6km radius of the proposed retention wall. The study site is geologically vulnerable and does not have the fundamental requirements to support a large reservoir and dam structure. The risk from experiencing reservoir collapse is significant, and it would release a catastrophic flow of approximately 229,612,176,263 billion $m^3$of water. Building such an invasive structure does not uphold environmental and human costs.

Ecologically, the proposed dam disregards legal codes that protect the habitat of the endangered Tricahue Parrot species inhabiting the reservoir site, making it subject to environmental charges and violations as well as major compensation costs for the riverine communities and associated ecological damage. This alone poses a great risk for the ecological integrity of local and endemic biodiversity.

The geomorphological and hydrologic changes caused by the dam will lower the formative base flow, creating inefficient flows unable to sustain aquatic and riparian biodiversity. Moreover, the impaired and lowered discharges will restrain the historical practice of whitewater boating activities and ecotourism that fuel the microeconomy of the area. The calculated risk of reservoir mismanagement could bring about the development of disease carrying organisms that threaten the health of local communities, aggravating human-related hazards. All of this will change the historical value and identity of the Los Queñes community, hindering its ability to prosper as a transboundary town and tourist destination, displacing its community and everything it stands for.

Chile has the luxury of possessing a heterogeneous topography, enabling multiple forms of energy generation, the majority of which are renewable and clean energy. The largest plant of solar panels in all of South America is currently located and operating in the North of Chile in the Atacama Desert. The plant has 668,160 solar panels scattered throughout the desert and comprises 576,8 hectares of physical terrain. It can generate up to 400 GWh per year, powering more than 200,000 Chilean homes. Other alternatives have been proposed including a synergistic use of multiple forms of solar, wind, tidal and geothermal energy coupled with prominent technology to mitigate energy losses. The country has the ability to meet its energy demands by utilizing the existing hydroelectric plants, managing and improving their efficiency and streamflow characteristics, as well as continuing to advance as an environmental and renewable energy leader for South America.

The Maule region of Chile is an important location for tourism and agriculture and its influence is expanding both nationally and worldwide. This region is renowned for its suitable soils for high-value agriculture (such as wine), making it an important contributor to the economy. Exploring this potential can further help communities in their fight to protect their sense of place and environment.

The contributions of this study support the existing assumption that underdeveloped communities are the targets for environmental degradation and over-exploitation of local natural reserves. In doing so, these communities are displaced without fair compensation creating a social injustice linked to environmental and ecological losses. This study provides the necessary background to empower their ambition to conserve their identities and offers technical and geospatial data to support the projections of hydroelectric damming development. The GIS applications performed for this study are an innovative approach for this type of research in Chile. The results and information gathered in this study are meant to be used by these grassroots communities and alliances as they continue their fight to protect free-flowing rivers.

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